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INFLUENCE OF FLY ASH ON COST-EFFECTIVE ROAD DESIGN

Sunil Kumar[1], Ms. Sheetal Verma[2], Dr. Ajay Swarup[3] ,Dr. Rajendra Singh kushwaha[4]
M Tech Scholar, Department of Civil Engineering, SOE, SSSUTMS[1]
Assistant Professor, Department of Civil Engineering, SOE, SSSUTMS[2]
HOD, Department of Civil Engineering, SOE, SSSUTMS[3]
Dean , School of Engineering SSSUTMS[4]

Abstract

This study explores the influence of fly ash on cost-effective road design, focusing on its impact on performance and economic benefits. The research assessed the physical and chemical properties of fly ash, identifying its primary components as silicon, aluminum, and iron. Ensuring that the soluble sulfate content remains within permissible limits, the study validated fly ash's suitability for road construction applications. The investigation highlighted fly ash's effectiveness in enhancing subgrade stabilization, especially in clayey soils with high plasticity indices. By replacing traditional materials with fly ash, the required pavement thickness was reduced from 500 mm to 300 mm, leading to significant cost savings. The cost analysis revealed that the use of fly ash could result in savings of approximately Rs. 6.20 lakhs per kilometer. Additionally, the study examined FaL-G concrete—a mixture of fly ash, lime, and gypsum—as an alternative to ordinary Portland cement. FaL-G concrete was found to potentially reduce construction costs by 30-60%. Overall, the findings demonstrate that fly ash offers substantial economic and performance advantages in road design, promoting more sustainable and cost-effective infrastructure development.

Keywords: *Fly Ash[1], Cost-Effective Road Design[2], Subgrade Stabilization[3], FaL-G Concrete[4], Pavement Thickness Reduction[5].*

1. Introduction

The search for sustainable and cost-effective materials in road construction has led to increased interest in utilizing industrial by-products such as fly ash. Fly ash, a by-product of coal combustion in power plants, has garnered attention for its potential to enhance road design efficiency and economic viability. This study investigates the impact of fly ash on road design, emphasizing its benefits in terms of performance improvements and cost savings. Fly ash is composed primarily of silicon, aluminum, and iron, and its effectiveness as a construction material is influenced by its physical and chemical properties. Key among these is the soluble sulfate content, which must be kept within specific limits to avoid potential corrosive effects on concrete and metal components. By ensuring compliance with these standards, fly ash can be safely and effectively incorporated into road construction. The study explores how fly ash contributes to subgrade stabilization, particularly in clayey soils with high plasticity indices. The integration of fly ash allows for a reduction in pavement thickness from 500 mm to 300 mm, which translates into substantial cost savings. Furthermore, the research examines the use of FaL-G concrete—a blend of fly ash, lime, and gypsum—as a viable alternative to traditional Portland cement, potentially reducing construction costs by 30-60%. These findings highlight the significant economic and performance advantages of incorporating fly ash into road design, offering a more sustainable approach to infrastructure development.

2. Methodology

To assess the impact of fly ash on road design cost-effectiveness, several key areas were analyzed. First, the physical and chemical properties of fly ash were evaluated, noting that it primarily contains silicon, aluminum, and iron. Fly ash's suitability for use as a filling material was determined by its soluble sulfate content, which should not exceed 1.90 grams per liter to avoid corrosive effects on concrete or metallic surfaces. Properties such as specific gravity, plasticity, and compressive strength were measured, and typical values were documented. The utilization of fly ash in roadworks was examined, focusing on its role in subgrade stabilization. Fly ash was found to enhance soil strength, particularly in clayey soils with a plasticity index above 8, and its interaction with lime improved performance in silty soils. The cost-effectiveness was analyzed by comparing the use of fly ash with traditional materials. The incorporation of fly ash reduced the required pavement thickness from 500 mm to 300 mm, resulting in significant cost savings. A detailed cost analysis showed a potential saving of Rs. 6.20 lakhs per kilometer. Additionally, using FaL-G concrete, a mix of fly ash, lime, and gypsum, was projected to cut costs by 30-60% compared to ordinary Portland cement, offering a more economical and durable solution for rigid pavement construction.

3. Result & Discussion

- **Physical and Chemical Properties of Fly Ash:** Fly ash primarily consists of silicon, aluminum, and iron. For use as a filling material, the soluble sulfate content in fly ash should not exceed 1.90 grams per liter. If it does, the fly ash should not be placed within 50 cm of concrete or metallic surfaces due to potential corrosive effects.The properties of fly ash can vary significantly based on factors such as the type of coal used, the degree of pulverization, combustion techniques, and collection and disposal methods. As a result, ash from different power plants can have notably different characteristics. Despite these variations, the following are typical properties of fly ash:

Table1.PhysicalandChemicalPropertiesofFlyAsh

Sl No	Description	Observedvalues
1	Specific gravity	1.90- 2.50
2	Plasticity	N.P*
3	Maximum dry density	0.95-1.60 gm/cm^3
4	Optimum moisture content	19%-38%
5	Permeability	$8x10^{-6}$to $7x10^{-4}$cm/sec
6	Uniformity coefficient	3.0-10.5
7	Compression index	0.05-0.40
8	Cohesion	Negligible
9	Angle of shearing resistance	300- 400
10	Coefficientof consolidation	$1.75x10^{-5}$to 2.00 $x10^{-3}$cm^2/sec
11	Silica (SiO_2)	46.50(%)
12	Alumina (Al_2O_3)	24.20(%)
13	Iron (Fe_2O_3)	10.00(%)
14	Calcium (CaO)	13.00(%)

15	Magnesium (MgO)	4.00(%)
16	Sulpher Content (SO_3)	Traces
17	Carbon	1.10(%)

- **Utilization of Fly Ash in Roadworks:** Fly ash is increasingly employed in the construction of various road pavement layers, particularly for filling and subgrade stabilization. Effective interaction between fly ash and subgrade soil can enhance the stabilization of the subgrade. According to the Ministry of Road Transport & Highways, Government of India, clayey soils with a plasticity index greater than 8 need to be treated and stabilized before road construction. When clayey soil reacts positively with the pozzolanic properties of fly ash, the soil's strength parameters improve due to the cementing effects of the pozzolanic compounds. Silty soil shows limited reaction with fly ash, but its performance can be enhanced by adding lime, which reduces leaching and improves strength and durability. Compacted fly ash can achieve sufficient shear strength, allowing embankments with a 2:1 (Horizontal) slope. However, the factor of safety for embankments constructed with fly ash should be no less than 1.25 under normal service conditions. Careful attention is needed to provide an earthen membrane over embankment slopes due to the high erosion potential of fly ash. Mixing soil with fly ash can improve the plasticity index, liquid limit, plastic limit, and C.B.R. (California Bearing Ratio) values to meet acceptable standards, contributing to more cost-effective road design.
- **Cost Effectiveness:** The cost of transporting fly ash limits the feasible distance for its economic use as a substitute for borrow soil. According to guidelines from the Ministry of Environment & Forests, Government of India, fly ash should ideally be used for roadworks, especially embankment construction, within a 100 km radius of thermal power stations. For effective use of fly ash in road construction, it is crucial to follow the Indian Roads Congress guidelines (SP:58, 2001). Fly ash should be used mandatorily in road embankments where it is available in sufficient quantities, unless technically unsuitable as determined by the Engineer-in-Charge. When fly ash is used to enhance subgrade material with higher C.B.R. values, it can significantly reduce the required pavement thickness, leading to stronger, more durable, and cost-effective roads. A comparative analysis, based on a typical cross-section of pavement (Figure 1), illustrates the cost effectiveness of using fly ash in the subgrade. The design data are assumed to provide a clear demonstration of the economic benefits.

Initial traffic in the year of completion of construction=42. Design life = 10 years.

Growthrate factor =6% (= 0.06).

Projected traffic=24(1+0.06)10= 75

C.B.R. value of sub grade = 2.8

Asperthedesignspecificationof“RuralRoadManual”specialpublication,IndianRoads Congress: SP-20 (2002), pavement thickness comes = 500 mm.

Topwidthofembankment=7.5m Height of embankment = 2.0 m.

Sideslope – 2H : 1V

Bottomwidthofembankmnt=15.5m Sideslopeearthoverthickness=1.0m Length of embankment = 1000 m.

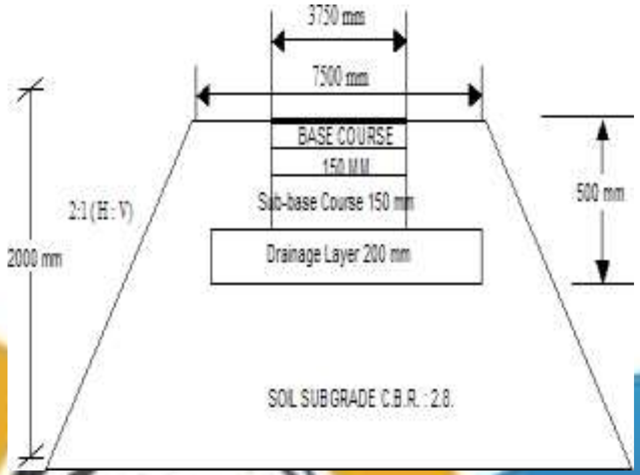

Figure1.Atypical crosssectionof pavementwithoutfly ash.

When fly ash is used as a substitute for soil in the subgrade, the C.B.R. value can increase significantly from 2.8 to 7. Consequently, the required pavement thickness can be reduced from 500 mm to 300 mm, enhancing cost-effectiveness in road design.

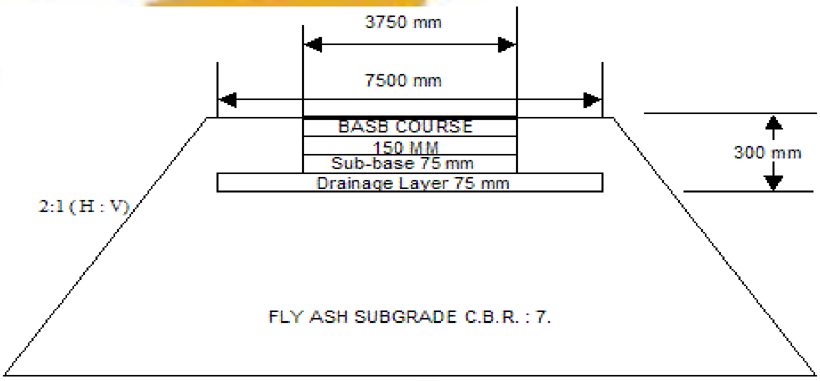

Figure2.Atypical crosssectionof pavementwithfly ash.

The cost savings for a road that is 3.75 meters wide and 1,000 meters long, with an average lead of sub-base material and drainage layer within 20 km, are estimated in Table 2.

Table2.Saving of cost due to ad option of fly ash

Item	Quantity (m^3)	Amount
Sand moorum	0.15 x 8.0 x 1000 = 1200	@Rs. 400.00 perm^3= 4.80 lakhs
Laterite	0.075x 3.75 x 1000 = 281.25	@ Rs. 500.00 per m^3= 1.40 lakhs Totalsaving:6.20lakhs

Hence saving per km of road = 6.20 lakhs.

Cost Effectiveness in Rigid Pavement Construction: In rigid pavement construction, fly ash can partially replace cement, sand, or both. For a typical rural road project using roller compacted concrete, approximately 25% of the cement volume can be saved by incorporating fly ash, resulting in a 15% reduction in construction costs when fly ash is sourced within a 10 to 15 km radius. Additionally, exploring FaL-G concrete—an admixture of fly ash, lime, and gypsum—could offer new opportunities in road construction. A mix ratio of 60:30:10 (fly ash:lime) has been shown to achieve significant compressive and flexural strength, as detailed in Table 3. Using FaL-G concrete in this ratio can replace ordinary Portland cement (O.P.C.) and is expected to reduce costs by 30-60%, enhancing overall cost effectiveness in road design.

Table3.CompressiveandflexuralstrengthofFal-Gconcrete.[WaterCementratio=0.50]

FaL-G mix	**7dayaverage compressive**	**14 days average compressivestrength**	**28 days average compressivestrength**	**28daysaverage flexural strength**
Proporti on strength	(MPA)	(MPA)	(MPA)	(MPA)
60 : 30 : 10	6.40	8.50	9.00	0.80

4. Calculation

The investigation into the use of fly ash in road design highlights its significant impact on both cost-effectiveness and performance. The study assessed the physical and chemical properties of fly ash, revealing that its composition mainly includes silicon, aluminum, and iron. Fly ash's suitability for use in roadworks was confirmed by ensuring its soluble sulfate content did not exceed permissible limits, thus preventing corrosive damage to adjacent concrete or metal structures. The analysis demonstrated that fly ash can substantially enhance subgrade stabilization, particularly in clayey soils with high plasticity indices. By substituting fly ash for traditional materials, the pavement thickness can be reduced from 500 mm to 300 mm, resulting in a marked cost saving. The cost analysis indicated that incorporating fly ash into road construction could lead to savings of approximately Rs. 6.20 lakhs per kilometer due to reduced material costs. Additionally, the use of FaL-G concrete, a blend of fly ash, lime, and gypsum, was found to be a promising alternative to ordinary Portland cement, potentially reducing construction costs by 30-60%. These findings underscore the economic and practical benefits of using fly ash in road design, making it a valuable material for cost-effective and sustainable infrastructure development.

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