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Application of Cementitious Materials for Stabilization of Soil in Flexible Pavement: A Review

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Abstract. The depletion of natural aggregates as a result of their widespread use in road construction has prompted the introduction of non-traditional materials. The use of treated soil in the subbase and base course of flexible pavement can significantly reduce natural aggregate consumption and construction cost. This article reviews the use of several cementitious binders, such as lime, cement, copper slag, dolime, ground granulated blast furnace slag, and steel slag to stabilize poor soil for the base and subbase layers of road pavement. The results from various researchers indicated an increase in the unconfined compressive strength (UCS), California bearing ratio (CBR), and resilient modulus (Mr) with the addition of cementitious binder and curing period. The use of binders to stabilize virgin soil for road pavement is well suited for sustainable construction as it meets the IRC standards along with its economic benefits. This study will help researchers and engineers choose the best binders for stabilizing poor soil to be used in road pavement applications.

Keywords: Stabilization; Unconfined compressive strength; Resilient modulus; California bearing ratio

1 Introduction

The most common pavement type for constructing roads and highways is a flexible pavement, which is used all around the world [1]. Flexible pavements make up around 95% of all roadways and comprise four layers specifically subgrade, subbase, base, and surface course. Flexible pavement requires a significant amount of natural aggregates, the extraction of which generates a large amount of waste. Additionally, laying these building materials produce pollution. Thus, resource depletion, environmental degradation, material waste, and rising material costs drive the demand for alternative materials that may be employed in flexible pavement [2], [3].
The management of waste products as a result of the industrial revolution is another ongoing problem. Because it is not biodegradable, industrial waste pollutes soil and groundwater, which could have an impact on human health and biodiversity due to its chemical components [4]. Additionally, landfills are the most dangerous step in the waste management process since they emit CO_2 and CH_4 when waste is disposed of in

them. The greatest way to reduce the heaps of waste is to avoid their creation in the first place, recycle them, and use them in other environmentally and economically efficient ways. Studies have shown that using secondary materials lowers the demand for conventional materials and lowers overall construction costs in addition to offering an effective method for disposing of waste.

Numerous studies have been conducted on the usage of cement and lime for the purpose of stabilizing soil for use in flexible pavement. In a study by Todingrara et al. [5], Laterite soil treated with lime-cement was evaluated in the laboratory and in the field for usage as a pavement foundation layer. On the basis of the results of unconfined compressive strength tests as well as field CBR and LWD tests, it was proposed that treated laterite soil with a lime and cement content of 12% and 5%, respectively, might be used as a pavement foundation layer to sustain vehicle loads. It is well known that the cement industry is the largest consumer of raw materials and energy. In addition, it plays a significant impact in climate change and global warming due to the emission of CO_2 and other greenhouse gases (GHGs) during its manufacturing [6], [7]. Due to these concerns related to cement production, industrial waste materials with high mineral or calcium content could be used as pozzolanic materials. Continuously, researchers have sought to discover new cementitious materials that might be utilized in the flexible pavement for soil stabilization. As a result of their effectiveness as cementitious or pozzolanic materials, a growing number of new materials consist of either waste or by-product components. In all types of pavement projects, various materials such as ground granulated blast furnace slag (GGBS), cement kiln dust (CKD), fly ash (FA), copper slag, and bottom ash is utilized alone or blended with cement and/or lime [8]. The experimental results obtained by Zumrawi and Hamza [9] showed that the optimum dosage of 15% fly ash with 5% cement had a significant improvement in strength and durability and can be considered a viable option for the stabilization of expansive subgrades.

This review study focuses on several wastes that are generated often throughout the world and may have cementitious qualities that allow for their usage in soil stabilization to support flexible pavement. By conserving natural resources and lessening landfill strain while retaining structural integrity, these cementitious materials may contribute to sustainability.

2 Use of cementitious materials in base layer of flexible pavement

As the top layer of a flexible pavement, the base course is subjected to the largest stresses. As a result, the utilization of a material of a high quality is an absolute requirement. It is observed that cement is available in abundant amounts and thus applied as soil stabilizer because it also provides the benefit of great strength and durability of pavement [10]. It has been also discovered that lime treatment in poor soil is most suitable for use in the construction of pavement. Furthermore, Mcdowell [11] suggests that the inclusion of fly ash, expanded shale fines, volcanic ash, and bituminous materials can improve the treatment of granular soils for the base course that does not react well with lime alone. It has also been discovered that the procedure of treating the soil with fly ash and lime is an appealing method when the project requires the enhancement of local soil in order to construct stabilized bases beneath pavements [12]. In order to determine the unconfined compressive strength, California bearing ratio, and resilient modulus of stabilized soil for use as base layers in highways, Arora et al [13] conducted a series of tests on soil-fly ash mixtures prepared with cement and lime as activators. The research concluded that the strength of a mixture is extremely sensitive to factors such as the time it takes to cure, the amount of compactive energy used, the percentage of cement, and the amount of water present during compaction. It was also revealed that the mixtures' strength is insufficient after lime treatment to be used for highway base design.

Several studies have investigated the feasibility of using various industrial waste products for soil stabilization in road pavements. Southwest Indiana loess soil stabilized with class C fly ash was examined by Zia et al [14] for its engineering properties to determine whether or not it would be suitable for use as a road base. Curing times for the samples ranged from 3 hours to 28 days after the fly ash and loess soil mixture was prepared. The results of the tests show that, depending on the loess material gradation and the fly ash characteristics, loess can be stabilized with Class C fly ash, provided that strength degradation is minimized or avoided. In a similar study by Sudla et al. [15], crushed slag and fly ash were combined with cement-stabilized soil in order to apply the soil mixture as pavement base. Laboratory and microstructural findings indicated that laterite soil (LS) stabilized with 3% cement (C) and blended with Crushed slag (CS) and fly ash (FA) at a ratio of 70:0:30 and 70:15:15 were the most suitable base material.

3 Use of cementitious materials in subbase/subgrade layer of flexible pavement

A pavement's subbase layer improves bearing capacity, provides drainage, diminishes the detrimental effects of frost action, and provides uniform protection to the top layers. The subbase is typically the thickest layer of a flexible pavement; thus, the economy of road building is dependent on the maximum exploitation of locally accessible resources in subbase construction. Traditional materials such as cement and lime are widely used to stabilize sub-base soil. To date, the majority of lime used for road stabilization has been hydrated lime, although quicklime and waste lime have also been used successfully. In addition to high calcium limes, dolomitic or magnesium limes have also been successfully employed. Patel & Shahu [16] attempted to use dolime particles to stabilize the problematic black Cotton soil so that it could be used as the subbase course for flexible pavements. To achieve this, for various trial mixes that were cured for up to 28 days, Atterberg limits, compaction properties, unconfined compressive strength (UCS), soaked CBR, and resilient modulus were studied. The Indian Road Congress specifications for use in the subbase layer of flexible pavements were met by black cotton soil stabilized with a minimum dolime content of 9%. Other wastes generated locally with a mineral composition similar to that of lime and cement can be utilized as an additive to improve the engineering properties of sub-base course. Industrial waste materials are abundant and include fly ash, stone dust, marble dust, coarse sand, and steel slag. These materials may be utilized in the subbase construction in order to reduce the overall cost of the roadway [17]. Sudla et al. [15] conducted a study to determine the viability of using crushed slag and fly ash to enhance the physical properties of marginal lateritic soil prior to cement stabilization as a subbase material in pavement applications. Based on geotechnical engineering laboratory tests, it was determined that 3% Cement-stabilized soil, when blended with 30% crushed slag replacement, is suitable for use as a subbase material. In a study conducted by Ã and Fındık [18], the ability of the novel pumice to stabilize Capali land material for use as a subbase layer was determined. The experimental results indicated that pumice can be used as a stabilization material when constructing a highway, and it was also observed that the local land material's strength increased with the addition of pumice. Similarly, Pai et al. [19] investigated the viability of using GGBS–lime-treated native soil in the subbase course of flexible pavement as part of an investigation encouraging the use of industrial byproducts. On the basis of California bearing ratio and unconfined compressive strength values, the native soil treated with 12% GGBS, 6% GGBS+ 3% lime, and 8% GGBS+ 4% lime attained the IRC minimum subbase material requirement.

The sub-grade is the pavement layer that serves as the foundation for the entire pavement system. The quality of pavement is dependent on its subgrade strength. The materials chosen for use in the construction of subgrade must possess sufficient strength and be cost-effective. The selected materials must also meet quality and compaction specifications. As the sub-grade supports the road pavements and the load of moving vehicles, it is crucial to improve the quality of weak sub-grade in order to increase its load bearing capacity. In a field study by Ifediniru and Ekeocha [20], improvement in the shear strength of subgrade soil was achieved by stabilization with 6 and 10% Portland cement. It was concluded that a linear relation existed between the cement content, strength of the improved soils, stabilization depth and the factor of safety. In an another research, Mandal & Singh [21] evaluated the usefulness of industrial wastes such as GGBS and fly ash as a soil admixture and focused on improving the engineering properties of soil to make it suitable for the sub-grade construction of roads, as well as minimizing the problems associated with dumping GGBS and Fly ash in open areas. I. Z. Yildirim and m. Prezzi [22] evaluated the field performance of electric-arc-furnace steel slag in combination with other industrial by-products as subgrade layer of pavement. Based on the laboratory test results, the soil stabilized with 7% steel slag and 3% Class C fly ash mixture was selected and implemented as a subgrade material in the pavement project. Based on the study of stabilization of problematic silty clay with fly ash-based geo-polymer and blast furnace slag, Sukprasert et al. [23] proposed that the use of waste by-products like blast furnace slag and fly ash to stabilize problematic soil will contribute to a significant reduction in pavement construction costs and the sustainable development of project life cycles.

4 Conclusion

Massive quantities of construction materials are required for the building, maintenance, and expansion of roads. However, conventional materials such as sand and gravel are in short supply for the construction of the subbase and base layers of flexible pavements due to factors such as diminishing resources, environmental concerns, etc. Consequently, the cost of high-quality natural building materials is rising, and they must be transported from distant quarries to the construction site. Therefore, it is essential to seek out resources that can contribute to sustainability by reducing consumption of natural resources. This paper compiles the various cementitious materials that are commonly used around the world for soil stabilization and their potential application in flexible pavement. The effectiveness of various materials as soil stabilizer has been evaluated, and it has been determined that lime and cement provide the most reasonable results of all the binders. For soil stabilization, however, supplementary cementitious materials have been used due to the high environmental impacts associated with cement and lime use. Based on the results of the unconfined compressive strength (UCS) and California Bearing Ratio (CBR) tests, it is determined that these materials are effective at stabilizing soft soils. Observably, the use of such cementitious binders increases the soil's strength and satisfies all the codal requirements for using such stabilized soil in pavement applications.

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