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Effect of styrene–butadiene copolymer latex on properties and durability of road base stabilized with Portland cement additive

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HIGHLIGHTS

- Cement additive and styrene–butadiene emulsion (Tylac® 4190) mixes investigated.
- Additive has improved the strength of mixes.
- WD tests on 4% Portland cement and 8% Tylac® 4190 mix reduce 86.99% water absorption.
- We develop nonlinear models to predict strength based on mixture parameters.

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ABSTRACT

This study investigated the effects of the type and amount of Portland cement and carboxylated styrene–butadiene emulsion (Tylac® 4190) on the short-term performance of a road base layer via a laboratory evaluation of stabilized soil-aggregate mixtures. Cylindrical specimens stabilized with Portland cement (0–6%), Tylac® 4190 (5–10%), and a mixture of both these additives were molded, cured for 7, 28, and 60 days, and then subjected to different stress sequences to study the unconfined compressive strength, indirect tensile strength, and indirect tensile resilient modulus. The long-term performance (durability) of stabilized soil-aggregate specimens was investigated by conducting wetting and drying (WD) cycling tests on 7-day-cured soil-aggregate specimens stabilized with cement and Tylac® 4190. The results revealed that the additives improved the strength of the specimens, which has been found to be an important quality indicator of road base mechanical properties. Results of tests conducted to assess the specimens' resistance to WD cycling showed that the addition of a 4% Portland cement–8% Tylac® 4190 mixture resulted in reductions of 86.99% in both water absorption and permeability, volume changes of 88.55%, and weight changes of 92.84% relative to a sample with only 4% cement after 12 WD cycles. This paper also presents the findings of a correlation study conducted for determining the influences of affective variables using nonlinear regression analysis to establish significant prediction models for strength based on mixture parameters.

1. Introduction

Factors such as an increased number of vehicles, traffic loading, and tire pressure have motivated pavement engineers to develop better technologies for increasing the pavement bearing capacity and improving short-term and long-term pavement performances. A variety of soils or granular materials are available for the construction of road bases, but they may exhibit inadequate properties, e.g., low bearing capacity, susceptibility to moisture damage, and susceptibility to environmental conditions, which would in turn result in substantial pavement distress and shortening of pavement life. However, the addition of a stabilizing agent can improve the properties of a soil-aggregate mixture. Soil-aggregate stabilizers are categorized as either traditional or nontraditional. Traditional additives include cement, lime, fly ash, and bituminous materials, whereas nontraditional additives include enzymes,

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liquid polymers, resins, acids, silicates, ions, and lignin derivatives. Among these different stabilizing materials, cement-treated base (CTB) develops significantly high stiffness and strength and exhibits good serviceability and high durability when used for pavement construction. Cement stabilization of soil was initiated on a trial basis in 1917, and since then, several works have been published on this topic [1–6]. Polymer stabilizers are typically vinyl acetates or acrylic copolymers suspended in an emulsion by surfactants. The polymer stabilizer coats soil-aggregate particles, and physical bonds are formed when the emulsion water evaporates, leaving a soil–polymer matrix. The emulsifying agent can also serve as a surfactant, improving penetration for topical applications and particle coating under admix conditions. The use of polymers as modifiers in new structures seems to be a promising strategy for improving the microstructure of mixtures and enhancing their durability [7–11]. Polymers have a significant effect on the workability and mechanical properties of soil aggregate–cement mixture. The literature usually refers to the more commonly used styrene–butadiene polymer materials. These materials are known to possess superior durability over ordinary Portland-cement-based concrete, and are resistant to acid attack, ice melting, and chloride diffusion. Several authors have shown that polymer impregnation of soil aggregate–cement materials may lead to increased durability depending on the type of polymers used. Previous studies have also indicated that the admixing of styrene–butadiene emulsion (SBE) latex into a mixture improved its resistance to chloride-ion penetration [10,12–16]. The molecular structure of SBE includes both flexible butadiene chains and rigid styrene chains, the combination of which lends many desirable characteristics to SBE-modified soil aggregate–cement materials, such as good mechanical properties, water tightness, and abrasion resistance [12,17–20]. A cement–SBE-treated base (CSBETB) can provide cost-effective solutions to many common designs and construction scenarios and impart additional strength and support without increasing the total thickness of the pavement layers. Depending on the requirements of a project, CSBETB can increase the construction speed and enhance the structural capacity of the pavement. In addition, a stiffer base reduces deflections due to heavy traffic loads, thereby extending pavement life [4,21–27]. CSBETB can also distribute loads over a wider area and reduce the stresses on the subgrade. It has a high load-carrying capacity, does not consolidate further under load, reduces rutting in hot-mix asphalt pavements, and is resistant to freeze–thaw and wetting–drying (WD) deterioration [28–30]. The goal of the present work was to assess the factors affecting the performance and strength of Cement–Tylac® 4190 treated base (CTTB) via laboratory tests aimed at determining its unconfined compressive strength (UCS), indirect tensile strength (ITS), and indirect tensile resilient modulus (ITRM), as well as WD cycling tests, which are the most frequently employed factors for assessing the degree of road base stabilization (RBS). Another goal was to determine the optimum contents of Portland cement and Tylac® 4190 in their mixture. The last but most important goal of the work was to compare the effects of these two additives on the soil-aggregate mixtures using significant prediction models.

2. Standard requirements for use of graded soil-aggregate in bases of highways

Quality-controlled graded aggregates are expected to provide appropriate stability and load support for use as highway or airport bases or sub-bases. This requirement delineates the aggregate size, variety, and ranges of mechanical analysis results for standard sizes of coarse aggregate and screenings of aggregates for their use in the construction and maintenance of various types of highways. The gradation of the final composite mixture is required to conform to an approved job mix formula within the design range prescribed in Table 1 in accordance with ASTM D 448, ASTM D 1241, and ASTM D 2940, subject to the appropriate tolerances.

3. Strength requirements for stabilized road base material

After obtaining the fitting aggregates and choosing the initial cement content by weight, the specimens were prepared according to their optimum dry density and the maximum moisture composition. The average UCS of the cement-treated specimens cured for 7 days was measured using a hydraulic compressive strength testing machine to detect the optimum content of cement. Table 2 lists the UCS requirements of CTB subjected to curing for 7 days. It should be noted that the UCS requirements depend strongly on the road class, and the material type relies heavily on the required UCS.

4. Materials and methods

To achieve the goals of this study, three major tasks—a literature review, laboratory investigation, and data processing and analyses—were accomplished. The soil-aggregate properties were evaluated prior to the design of the mixture, and those physical properties namely index test. The cement used was type II Portland cement. The nontraditional stabilizer used, Tylac® 4190, is a water-based liquid emulsion and is a novel additive in this method. To evaluate the short-term performance of the stabilized soil-aggregate specimens under various stress sequences, the UCS, ITS, and ITRM were determined. The long-term performance of these specimens was investigated by subjecting them to repeated WD cycles. Finally, on the basis of the results of data analysis, significant models were developed to demonstrate the relationship among the characteristics of the mixture.

4.1. Aggregates

Crushed granite aggregates from the Kajang Rock Quarry (Malaysia) were used as the granular base layer material in this study. Fig. 1 illustrates the grading curves of soil-aggregates within the limits specified by the ASTM standards for highways and/or airports. One of the most important factors affecting the performance of CTB is its organic content. In all probability, a soil with an organic content greater than 2% or having a pH lower than 5.3 will not react normally with cement [32]. A pH greater than 12.0 for a mixture indicates that the organics present will not interfere with hardening [33,34]. In this study, the results of a pH test conducted according to ASTM D 4972 indicated that adding cement to the soil-aggregate increases the pH from 8.26 to 12.13 whereas adding a cement–Tylac® 4190 mixture to the soil-aggregate increases the pH from 8.26 to 12.39. This clearly shows that the additives have a positive effect in the mixture.

The general properties of the used soil-aggregates are summarized in Table 3. Table 3 lists the most correlated geotechnical properties of the soil-aggregates used in this study.

4.2. Portland cement

Various kinds of Portland cement have been used effectively for soil-aggregate stabilization. In this study, type II Portland cement was used as a treatment material for the granular mixtures because of its higher sulfate resistance, moderate heat of hydration, and mostly equivalent cost in comparison to other types of Portland cement. A high sulfate content of soil results in swell and heave problems, and it can have a deleterious influence on cementing and stabilization mechanisms. The Portland cement used in this study was required to conform to the respective standard chemical and physical requirements prescribed by ASTM C 150 and ASTM C 114. The cement would be rejected if it does not meet any of the necessary specifications. The properties of type II Portland cement are presented in Table 4.

4.3. Water

The mixing water used for these tests should be free of acids, alkalis, and oils, and in general, it should be suitable for drinking, according to ASTM D 1632 and ASTM D 4972. According to ASTD D1193, water is classified into four grades-types I, type II, type III, and type IV-depending on its physical, chemical, and biological properties. All the mixed water used for these test methods should be ASTM type III or better. Water prepared by distillation is of type III.

4.4. Tylac® 4190

Tylac® 4190 is proposed as a polymer modifier for hydraulic cement mixtures or tile mortar adhesives. It is surfactant-stabilized styrene–butadiene copolymer latex used in concrete, mortar, grout, and cement mixtures; when used properly (mixed