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Evaluation of cement-treated mixtures with slow setting bitumen emulsion as base course material for road pavements

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HIGHLIGHTS

- The long-term performance of CBETB was investigated.
- The use of 4% C–3% BE in the pavement base layer are recommended.
- WD tests on 4% C–3% BE mix resulted in a weight losses of 211.95%.
- Additive remarkably improved the permanent deformation of CBETB.
- Zhou three-stage model was developed for DC and WT of CBETB.

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ABSTRACT

This study investigated the effects of the addition of a bitumen emulsion and Portland cement on the long-term performance of road base. The specimens stabilized with Portland cement (0–6%), bitumen emulsion (0–6%) and Portland cement–bitumen emulsion mixture were subjected to different stress sequences in order to study the unconfined compressive strength (UCS), flexural strength (FS), wetting and drying (WD), soaked and unsoaked California bearing ratio (CBR), dynamic creep (DC), and wheel-tracking (WT) characteristics of 7-day-cured specimens. The results of UCS, FS and CBR tests revealed that the additives significantly improved the strength of the mixture. The WD cycling tests showed that the addition of a 4% Portland cement–3% bitumen emulsion mixture resulted in a 179.4% reduction in water absorption, a volume change of 256.3%, and a weight change of 211.95% as compared to the sample with 4% cement after 12 WD cycles. The permanent strain behavior of the samples was assessed by the Zhou three-stage model. The results of DC and WT tests showed that the permanent deformation characteristics were considerably improved by the addition of a 4% Portland cement–3% bitumen emulsion mixture, which resulted in reduction of permanent strain of the mixture. Therefore, this research presents an environmentally friendly additive with outstanding engineering properties for use in road bases.

1. Introduction

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, liquid polymers, resins, acids, silicates, ions, and lignin derivatives. Among these different stabilizing materials, a cement-treated base (CTB) material has significantly high stiffness and strength and exhibits good serviceability and high durability when used for pavement construction. Cement stabilization of soil was first used on a trial basis in 1917, and since then several works have been published on this topic [1–6]. Recently, heavier lorries with exceeding tyres pressures, heavy traffic loads, environmental effects, and high cost of petroleum-derived materials due

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to the energy crisis have motivated researchers to develop more cost-effective asphalt pavement treated technologies. In this context, cold-in-place stabilization is one of the most capable technologies for its technical reliability, cost-effectiveness, and low environmental impact. In fact, it was recognized in various studies that in road base treatment applications, bitumen emulsion–cement mix modifications improve aggregate bonding, thermal susceptibility, abrasion resistance, and resistance against bleeding, to provide adequate flexibility or to be utilized as an adhesive material [7–9]. However, the type of bitumen emulsions, the compatibility between bitumen and cement, and the amount of bitumen emulsions to be added to the mixture must be carefully designed. The environmental benefit of asphalt emulsion is particularly positive when used for in-place or on-site techniques that avoid the energy usage and emissions associated with heating, drying, and haulage of aggregate. Emulsified asphalt must revert to a continuous asphalt film in order to act as cement in road materials which inclusive removal of the water (breaking), flocculation and coalescence of the emulsion droplets. The droplets are concentrated; leading to coalescence as water leaves the system. The basic mechanism for breaking slow-setting emulsions can be evaporation and absorption of water by the aggregate. However, the emulsifier absorption onto the surface of aggregate, the emulsion droplets movement to the surface of aggregate, and the chemical reactions (pH change) between the bitumen emulsion and the soil aggregate contribute to the emulsion setting [7,8]. The setting speed and curing procedure depend on the bitumen emulsion reactivity, aggregate reactivity, bitumen viscosity, environmental effects (humidity, wind, temperature, etc.) and mechanical reaction. Less viscous asphalts tend to give faster coalescence. In other words, in order to enable the asphalt binder to properly disperse in the aqueous phase, it is necessary that its viscosity be relatively low. In addition, lower viscosity asphalts coalesce more rapidly than high viscosity asphalts and allowing it to be used at lower temperature in the mixture [7,10]. The strength of the reaction of emulsion with aggregate is in many cases sufficient to squeeze the water from the system. A considerable amount of research has been expended to elucidate the mechanism of setting and curing of asphalt emulsion [7,10]. The relative timescale of flocculation (setting) and coalescence (curing) depends on the system, but in general, flocculation is the more rapid process in which some water can be expelled from the system and some cohesive strength develops, followed by a slower coalescence process, which results in a continuous asphalt phase. This asphalt phase must also adhere to the aggregate. Bitumen emulsion–cement compatibility can be evaluated by the stability of emulsion when blended with cement. The stability of the blended bitumen-emulsion and Portland cement must be evaluated as the bitumen emulsion stability will be affected by the cement hydration consumption of water, pH change caused by the Portland cement, and particle charges in the blend [8,9,11–15]. Water in bitumen emulsion consumes due to cement hydration, which reduces the emulsion spaces between the micelles and increases the incorporation of asphalt micelles. Several researches indicated that cement–bitumen emulsion treated base (CBETB) can provide cost-effective solutions to many common designs and construction situations and provide additional strength and support without increasing the total thickness of the pavement layers [8,16]. In addition, depending on project needs, CBETB increases the construction speed, enhances the structural capacity of the pavement, or in some cases reduce the overall time project. A stiffer base reduces deflections due to heavy traffic loads, thereby extending pavement life [4,17–22]. Moreover, CBETB can distribute loads over a wider area and reducing 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, wetting–drying deterioration [23–25]. Earlier studies [8,9,26–30] clearly demonstrated various benefits from cement–bitumen emulsion addition. This study has extended in terms of both quantifying performance-based mechanical properties and investigating the effects of variables on CBETM using significant predicting model which is not published earlier. The goals of the present work were:

- To assess the factors affecting the short-term performance and strength of a cement–bitumen emulsion-treated base (CBETB) via laboratory tests aimed at determining its unconfined compressive strength (UCS), flexural strength (FS), and unsoaked California bearing ratio (CBR).
- To investigate the long-term performance of stabilized soil-aggregate specimens by conducting soaked CBR, DC, and WT tests on specimens cured for 7 days; these are the most frequently employed factors for assessing the performance of road base stabilization (RBS).
- To study the durability of CBETB subjected to wetting and drying (WD) cycles. The durability of CBETB can be significantly affected by environmental conditions, which considered to evaluate these effects on the performance of CBETB.
- To determine the optimum content of Portland cement and bitumen emulsion in CBETB.
- To compare the effects of the additives on the mixtures using significant prediction models.

WD cycles can be destructive and damage the construction of RBS. However, there are no previous studies showing the behavior of CBETB subjected to WD cycles and permanent deformation of the pavement structure. Hence, it is important to study the effect of environmental conditions and evaluate the permanent strain potential of CBETB.

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 highway and airport bases or sub-bases. This requirement delineates the aggregate size, variety, and ranges of mechanical analysis results for standard sizes of coarse aggregates and screenings of aggregates used 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 maximum dry density and the optimum moisture

Table 1
Grading requirements for final mixtures [31].

Sieve size (square openings)	Design range (mass percentages passing)		Job mix tolerances	
	Bases	Sub-bases	Bases	Sub-bases
50 mm (2 in.)	100	100	−2	−3
37.5 mm (1 1/2 in.)	95–100	90–100	±5	+5
19.0 mm (3/4 in.)	70–92	NA	±8	NA
9.5 mm (3/8 in.)	50–70	NA	±8	NA
4.75 mm (no. 4)	35–55	30–60	±8	±10
600 μm (no. 30)	12–25	NA	±5	NA
75 μm (no. 200)	0–8	0–12	±3	±5