Jurnal Teknologi

Full paper

The Potentials of Portland Cement and Bitumen Emulsion Mixture on Soil Stabilization in Road Base Construction

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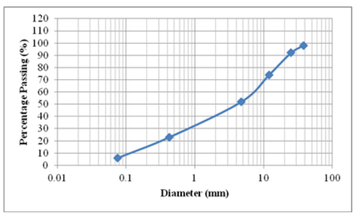
Article history

Received :20 August 2013
Received in revised form :
25 September 2013
Accepted :15 October 2013

Graphical abstract



Abstract

Recycled road based material requires a stabilizing effect in order to provide a longer life to pavements. This is done by improving its strength and reduces its water vulnerability. One of the most popular techniques to achieve this is by using soil stabilization. This research aims to analyze in details the soil stabilization method which utilizes Portland cement and bitumen emulsion in improving soil properties. As a result, this will increase the pavement bearing capacity (conducted via laboratory research). The combination of Portland cement and bitumen emulsion are beneficial for the purpose of increasing the stiffness and also the elasticity of soil stabilized layer. In order to examine this, two steps were undertaken, first, by examining the Unconfined Compressive Strength (UCS) and Modulus of Elasticity (ME) on samples mixed with soil aggregates comprising Portland cement and bitumen emulsion. Next, the data collated was analysed and the graph plots were presented as to show the optimum value of Portland cement and bitumen emulsion used in soil stabilization. The major findings of this research showed the importance of soil stabilization using Portland cement and bitumen in improving pavement's performances by increasing bearing capacity of its layer. The findings revealed that overall; the optimum value of Portland cement and bitumen emulsion utilized in base Soil stabilization method is 3% and 3% respectively. With this method, the duration time of the project can be reduced and subsequently the project cost may be also reduced.

Keywords: Soil stabilization; Portland cement; bitumen emulsion; pavement bearing capacity; unconfined compressive strength

■1.0 INTRODUCTION

The stability of the underlying soils is significantly affected by the long-term performance of pavement structures. It must be stressed that stabilization is found to be an alternative specifically for soil improvement which is effective in terms of its properties and the engineering properties derived from stabilization are vary widely. The reason for this can be found in soil composition that can be described as heterogeneous, differences in geological deposits' heterogeneity, micro structure, macro structure, physical and chemical interactions that can be found between the soil and any possible stabilizers [1]. A variety of stabilization techniques are utilized to reduce the detrimental effects of the expansion behaviour of the soil on the structures which include chemical stabilization (use of cement, lime, bitumen and other additives), soil replacement, recompacting, prewetting, and preloading of the structures [2]. For many soils, more than one stabilization agent may be effective, and financial considerations or availability may be the determining factor to use [3]. At this time, the popularity of conventional cementations stabilization has become well known and challenged by an innovative soil improvement method, known as foamed bitumen stabilization [4].

Nomenclatures

UCS	Unconfined Compressive Strength, KP_a
ME	Modulus of Elasticity, N/mm^2
ASTM	American Society for Testing and Material
C_u	Coefficient of uniformity
C_c	Coefficient curvature
SGC	Superpave Gyratory Compactor
d	Diameter, cm
H	Height, cm
A	Area, cm^2
W	Weight, gr
ρ_n	Density , gr/cm^3
V	Volumes, cm^3
F	Maximum load, KN
ΔH	Reduction in height of test specimen, mm
D60	Grain diameter at 60% finer
D30	Grain diameter at 30% finer
D10	Grain diameter at 10% finer

■2.0 SOIL STABILIZATION

Soil stabilization is an important consideration for improving the engineering properties of soils used for pavement base. There may be a number of stabilizers applicable for one type of soil based on soil granularity, plasticity, or texture. It has the purpose of increasing strength and durability to prevent erosion and dust generation [5]. The addition of stabilizing agents can result on the alteration to the properties of soils, such as plasticity, compressibility, and permeability; ordinary Portland cement, lime, and bitumen, all of which have been used extensively [6]. Furthermore, soil stabilisation can be categorised as vibration, surcharge load, structural reinforcement improvement by structural fill, admixtures, and grouting and others. They can be utilized for different purposes by enhancing some elements of the soil behaviour and upgrading the strength and properties of soil [7]. A part of Pavement materials are built from clay soils which can result in notable pavement distress due to moisture-induced changes in volume and support values of low sub-grade. Portland cement is recognized for its capability to provide plastic clays' stability [8]. Findings from research have shown that the increase in strength of cement-stabilized soil is due to the reactions of physico-chemical in terms of hydration and cement hardening. Besides this, the substances that go through the process of interaction between the substances from soil and the products that are derived from hydrated cement contributed to those processes [9]. Using too much cement in stabilized material has the tendency to deteriorate easily due to the shrinkage cracks which is a big problem for pavement from water penetration. This problem can be avoided when bitumen emulsion is used [10]. In terms of using bitumen emulsion, the basic mechanism is waterproofing which durability can be improved by increasing the soil resistance to the detrimental effects of water such as volume. The mixture of cement and bitumen emulsion has the function of raising both the stiffness and elasticity of the layer that has been stabilized.

■3.0 METHODS AND MATERIALS

In this study, the relationship between the soil stabilization method which using Portland cement and bitumen emulsion were observed and the results were compared with the more traditional techniques by examining the increase in the stiffness and elasticity of the stabilized layer. The materials' properties needed for the evaluation of the structural capacity comprise material's strength and stiffness whereby the parameters were derived from samples testing obtained in the laboratory in situ [11]. The optimum value of Portland cement and bitumen emulsion to be used in soil stabilization was tested via laboratory test and analyses. For the purpose of measuring the shearing resistance of cohesive materials, unconfined compression strength test was conducted. In addition, an axial load was applied using either strain-control or stress-control methods [10]. A mixed design of stages was used in this research which can define and determine the best value percentage of cement and bitumen emulsion by using Unconfined Compressive Strength (UCS) test. In this study, 164 samples with different percentages of Portland cement and bitumen emulsion were made. In addition, samples were prepared according to American Society for Testing and Material (ASTM), comprised of soil aggregates, Portland cement and bitumen emulsion. Figure 1 shows The Gradation limit of aggregate. Table 1, Table 2 and Table 3 show the specifications of soil aggregates, bitumen, and bitumen emulsion respectively.

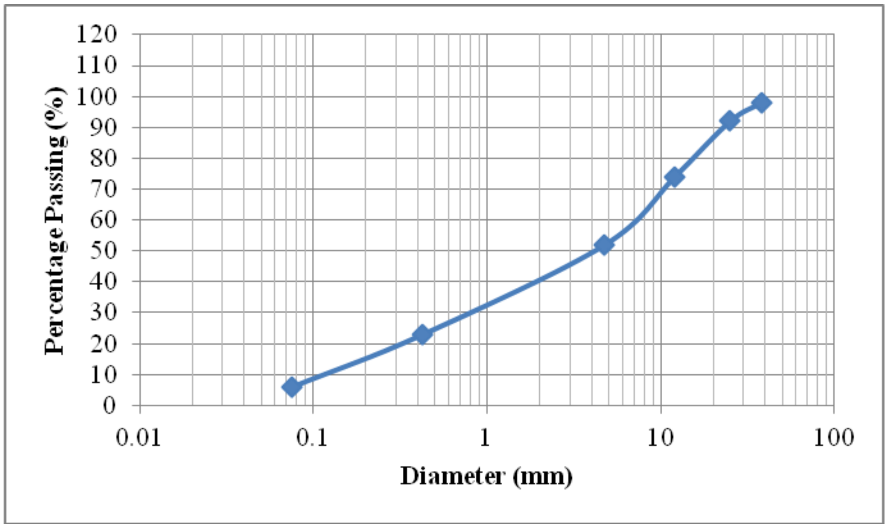


Figure 1 Gradation limit of aggregate

Using the size of the grain's distribution and the subsequent equations were applied to calculate the coefficient of uniformity (Cu) and coefficient curvature Cc.

$$C_u = \frac{D_{60}}{D_{10}}$$

$$C_c = \frac{D_{30}^{\ 2}}{D_{60} \times D_{10}}$$

Where, D60 is grain diameter at 60% finer, D30 is grain diameter at 30% finer and D10 is grain diameter at 10% finer. After the process of curing, specimens were left overnight in an air cabinet at the temperature of 25°C prior to the testing period. Next, each specimen was measured in terms of the height at four evenly-spaced places around the circumference and the calculations of the average height, h (cm); measure the diameter, d (cm) and the mass by weighing, M (g) were made. It must be noted that the mould is a cylinder with 150 millimetre diameter and 65 millimetres and 300 millimetre height which is one of the standard sizes for using Superpave Gyratory Compactor (SGC) machine. The formula to determine the volume and the weight of the samples are stated below:

Table 1 Specification of the soil aggregates

Unified classification	Plasticity	Sand Equivalent	D60(mm)	D30(mm)	D10(mm)	CC	CU
SW	NP	74	7	1	0.13	1.09	54

Table 2 Bitumen 60-70 specification

Specification	Units	Specification	Test Method
Penetration At 25°C	mm	90	ASTM D5
Ductility At 15°C	cm	108	ASTM D 113
Ductility At 25°C	cm	100	ASTM D113
Softening Point	°C	50	ASTM D 36
Flash Point	°C	276 min	ASTM D 92
Wax content	%wt	2.0 max	DIN 52015
Solubility In trichloroethylene	%wt	99.5 min	ASTM D 2042
Specific gravity at 25 °C	°C	1.03	ASTM D 70

Table 3 Emulsion specification

Specification	Bitumen(60-70)	Water	Emulsifier	Solvent	Acid(Hcl)
Producing temperature(°C)	145	28	35	Octane-40	35
Unit weight (gr/cm3)	0.95	1	1.07	0.8	1.15
Percentage by weight (%)	58.5	39	1	1.3	0.20

3.1 Mix Design

In terms of the process of mixing the materials, each sample was mixed and compacted in the standard mould and made into the size of 15 cm diameter and 15 cm height for UCS and 15 cm diameter and 7 cm height for ME. Table 4 shows the materials content. As the initial step, the soil grains in each mould were soaked in maximum water content and cement, with emulsion already mixed in the mixer for the duration of three minutes they were subsequently compacted with Superpave Gyratory Compactor (SGC). As the next course of action, the samples went through the process of curing for 6 days and 27 days. After that, they were tested accordingly and the Unconfined Compression Strength of each sample was recorded. The findings in terms of the percentages and the weight of water and Portland cement are depicted in Table 5. The raw data were recorded in spreadsheet format with one column for the gyration number and another for the corresponding height. It must be stressed that samples should be compacted as close to 98% Gmm as possible, however they should not exceed a threshold of 600 Gyrations Sample volumetric properties and shall be obtained using ASTM D1074-02 standards. Figure 2 shows a typical sample mix in the form of 15 cm in diameter and 7 cm in height after compaction.

Table 4 Materials content

Cement (%)	*Emulsion (%)	Sample (gr)	Cement (gr)	Optimum water (%)	Bitumen emulsion (gr)	Water (gr)
0	0to6	2500	0	3.9	0to150	102.5
1	0to6	2500	25	3.9	0to150	102.5
2	0to6	2500	50	3.9	0to150	102.5
3	0to6	2500	75	3.9	0to150	102.5
4	0to6	2500	100	3.9	0to150	102.5
5	0to6	2500	125	3.9	0to150	102.5
6	0to6	2500	150	3.9	0to150	102.5

*Bitumen emulsion was added at different proportion (0% to 6%) for each percentage of cement

Figure 2 Superpave Gyratory Compactor (SGC)

3.2 Curing Samples

For the purpose of curing the samples, the steps below were undertaken: For 12 hours, the compacted samples were kept in an ambient temperature. Next, from the moulds, the samples were extruded. The first batch of samples was covered using plastic bags at temperature of 20º C for the duration of 5 days. The humidity was kept at 95% and the same was done to the second batch for the duration of 26 days. For both series, the samples were kept in the refrigerator for 24 hours with temperature of 5º C prior to the testing process.

3.3 Unconfined Compression Strength (UCS)

UCS test was conducted on samples after the process of curing in order to draw graphs in determining the optimum value of Portland cement and bitumen emulsion. Further details and vital test specification are sorted based on laboratory standards such as ASTM D 1632-33, ASTM D1074-02 and ASTM D2166-06. The cylindrical sample was put to the test under axial stress and at a breaking point for this purpose. The following Equation is used to derive the UCS values.

$$UCS = \left(\frac{F}{A}\right) \times \left(1 - \left[\frac{\Delta H}{H}\right]\right)$$

Further UCS values were calculated based on the following steps as shown in Table 5. Subsequently, the test results were saved in spreadsheets whereby the load and strain were included.

Table 5 UCS calculation

1	2	3	4	5
F_i	ΔH_i	$\left(1 - \left[\frac{\Delta H_i}{H_i}\right]\right)$	A_i	UCS_i

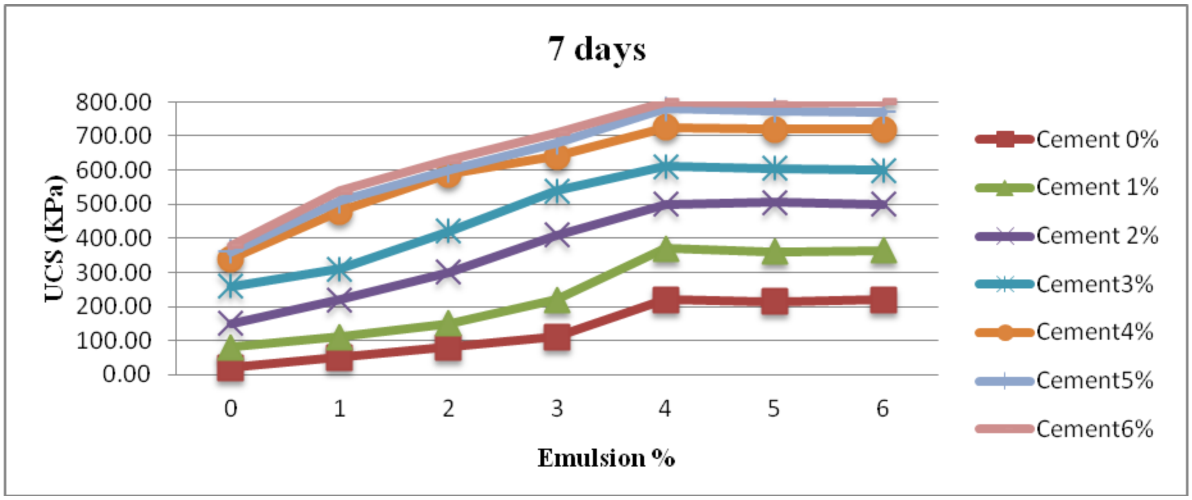


Figure 3 Effects of Cement - Bitumen Emulsion on UCS (7 days)

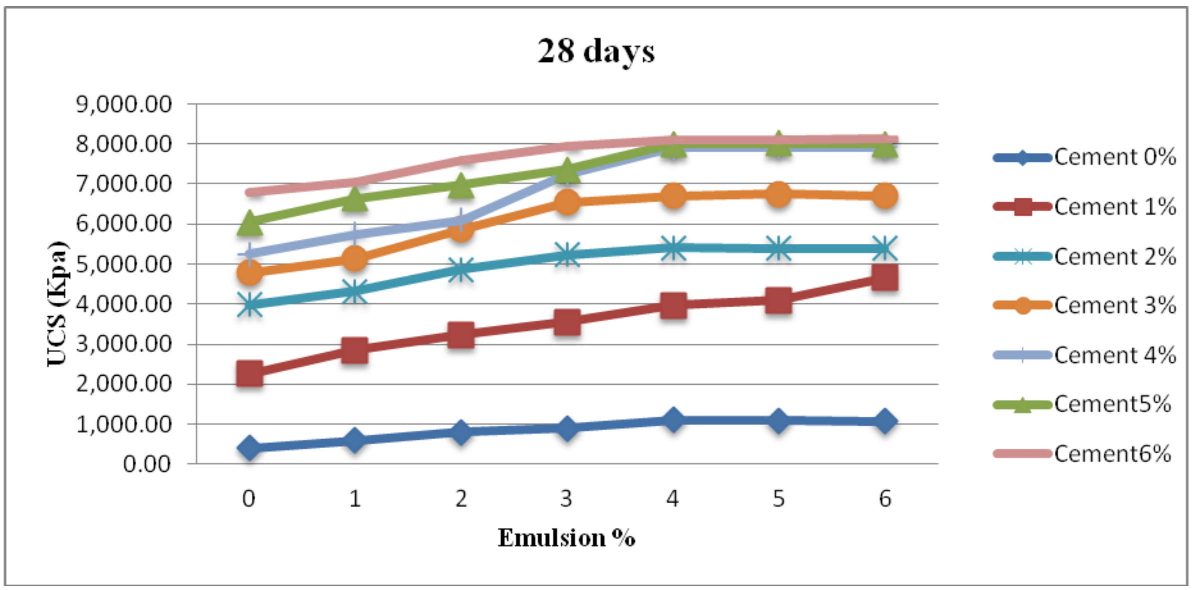


Figure 4 Effects of Cement - Bitumen Emulsion on UCS (28 days)

The UCS versus bitumen emulsion for variety of cement percentages are shown in Figures 3 and 4. Based on all of the plot curves, the results indicated that the increase in UCS was in tandem with increase in value indicated from the cement. The plot curves indicated that the maximum value of UCS was reached when the bitumen emulsion reached 3%. The optimum 3% value for bitumen emulsion was confirmed when the UCS test was conducted.

■4.0 MODULUS OF ELASTICITY

To determine the modulus of elasticity a Universal Testing Machine (UTM) was used. ME test was conducted on samples after the process of curing in order to draw graphs in determining the optimum value of Portland cement and bitumen emulsion.

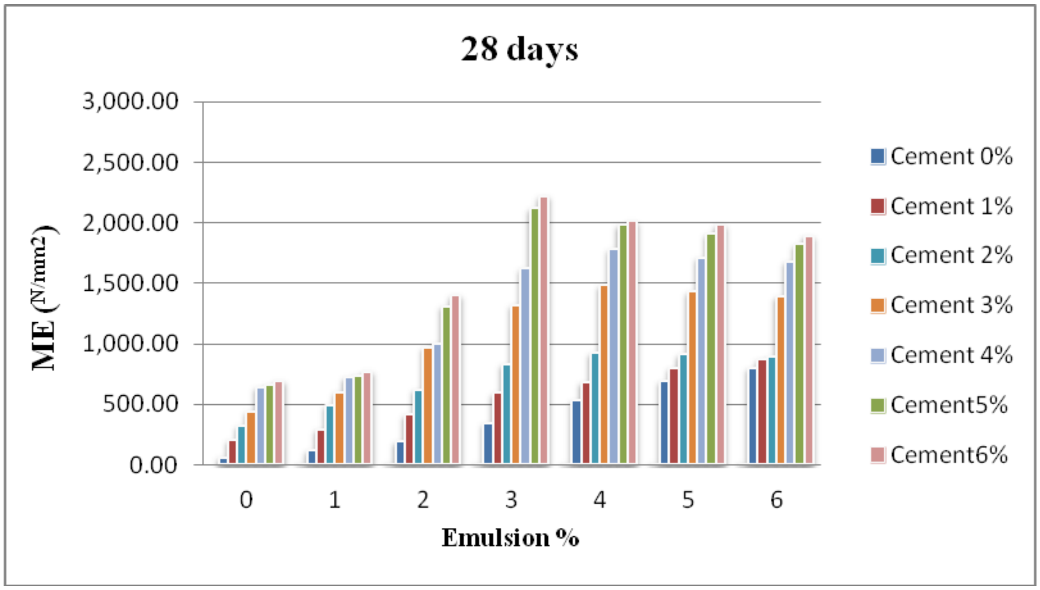


Figure 5 Effects of Cement - Bitumen Emulsion on ME (28 days)

The ME versus bitumen emulsion for variety of cement percentages are shown in Figure 5. Based on all of the plot curves, the results indicated that the increase in ME was in tandem with increase in value indicated from the cement. The plot curves indicated that the maximum value of ME was reached when the bitumen emulsion reached 3%. This might be due to the chemical reaction of cement-bitumen emulsion in the mixture. The optimum 3% value for bitumen emulsion was confirmed when the ME test was conducted.

■5.0 DISCUSSION AND RESULT

The findings revealed that overall; the optimum value of Portland cement and bitumen emulsion utilized in base Soil stabilization method is 3% and 3% respectively. With this method, the duration time of the project can be reduced and subsequently the project cost may be also reduced. The findings from the tests (UCS) and (ME) showed that soil stabilization is an effective treatment to be applied to the soil in order to improve its strength and may reduce water vulnerability. In sum, the results of UCS and ME test show that the combination of Portland cement and bitumen emulsion as the base of stabilization increases the bearing capacity of the pavement effectively. This method has resulted in considerable increase in some of the equivalent standard axle loads that is allowed on pavements and consequently, results in the increase in the lifetime of the road.

Acknowledgment

The authors would like to express appreciation to the UKM's Sustainable Urban Transport Research Centre (SUTRA) / Department of Civil and Structural Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia for providing facilities to conduct this study.

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