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Improvement in CBR Value of Sub-Base Soil using Concrete Slush Waste (CSW)

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Abstract: The earthen material and its properties are essential in the design of the pavement system as they affect the pavement's strength and stability, even under adverse traffic and environmental conditions. Unfortunately, earthen on-site has not always had a suitable property to be used as a good quality material for road pavement construction. Thus, soil efficiency should be enhanced by modification and stabilisation techniques to sustain structure without failure thereon. The present study was performed to evaluate the appropriateness and effectiveness of concrete slush waste (CSW) as a by-product construction material obtained from a concrete batching plant at Durable Mix, Panchor, Muar, Johor, and it was investigated as an additive material for road sub-base. This study aimed to improve the strength performance of locally available soil around Pagoh, Muar, Johor, Malaysia. The general properties tests include hydrometer, Atterberg limit, and a specific gravity test that were conducted to identify and classify the type of soil used throughout this study. Subsequently, standard compaction and California bearing ratio tests were performed to study the effect of CSW on the geotechnical properties of stabilised-soil. Based on the index properties results, the soil sample used is graded as high plasticity clay soil, consisting of liquid limit (LL) more than 50%, plastic limit (PI) more than 30 %, a specific gravity of 2.56, and 45.2% fines particles passing through sieve No. 200. The compaction results showed that the maximum dry density (MDD) decrease and optimum moisture content (OMC) value increased when mixed with CSW. The results show that the CBR value significantly increases from 9.70% to 45.44%, with the rise in CSW percentages from 0% to 12%, and it was achieved the highest value at 1.2% of CSW content. The findings show that the CWS has been proven as a potential material in enhanced soil efficiency, which meets the necessary strength recommended by the Malaysian Public Works Department (JKR) for road sub-base. Besides that, by utilisation of CSW in the soil would also encourage sustainable and cost-effectiveness practice in road construction.

Keywords: Earthen material, concrete slush waste, road sub-base, California bearing ratio.

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1. Introduction

Soil is a heterogeneous, complex and unpredictable material which depends on the vagaries of nature and environmental condition (dry and wet). Kollaros [1] and Ismail [2] stated that the soil's performance differs from one point to another even at the same area, but also from one location with depth and with a climatic change, loading and drainage conditions. However, certain types of soils include soft clays, high plasticity soils and highly organic soils are deemed unfit for use as fill materials in construction applications. The structures that constructed on such kind of soils tend to cause soil failure and settlement, especially when they are subjected to additional load and external impact. In addition, if not properly handled during the design stage, it will trigger a negative impact on pavement performance [3]. Figure 1 shows the pavement distress that occurs on Panchor-Muar road a month after completion of the repair work. Based on the observation, it is maybe due to the type and poor performance of soil, and poor drainage system, which the soil tends to be saturated and soft at high moisture content.

Fig. 1 - Pavement failure at Panchor-Muar road

Nowadays, there are various stabilisation technology are adapted to improve the engineering characteristics of soil, such as preloading, reinforcement, sand or stone column, piles, vertical drains, and biochemical stabilisation [2,4]. Soil stabilisation is the method of enhancing the physical and engineering properties of soil to the desired performance for the specific construction purpose. Nevertheless, since a couple of years ago, stabilisation techniques have gained more popularity due to its excellent engineering performance and economic maintenance costs [5]. Construction Research Institute of Malaysia [6] and Latifi [7] stated that the chemical stabilisers are categorised as conventional and unconventional methods. The conventional stabilisers include cement, fly ash, and lime, while unconventional stabilisers additives are liquid polymers, resins, acids, enzymes, and lignin. Shalabi *et al.* [8] reported that numerous researches have been carried out to study the effect of cementations additives on the geotechnical properties of soils used for road and foundation construction. Most of previous researches recorded a substantial improvement in the strength and stiffness and a decrease in the compressibility of the stabilised soils. There are a few sustainable soil stabilisation methods that have been practiced by road construction industries for the past decades by utilise recycled waste materials, including construction waste, agricultural waste, and municipal solid waste as sustainable and cost-effectiveness solution.

Therefore, this study adopts an approach in using construction waste as a potential additive material to strengthen the soil performance in the most economical way. Due to the construction waste generation in Malaysia is one of the significant pressing environmental issues caused by the rapid growth of the construction industry [9,10]. Since a few years ago, the amount of construction waste getting increased in conjunction with the demand for houses and major infrastructure projects [11,12]. As a result, the issues of illegal dumping have swelled rapidly around the world, as reported by [13,14]. Rahmat & Ibrahim [15] reported that nearly 50% of the illegal dumping volume in the Johor district consisted of construction waste. Furthermore, inadequate landfill spaces have nowadays also become a serious concern due to improper waste management. As an alternate way is to recycle and reuse such waste in the construction industry is highly desired.

Hence, the present study uses concrete slush waste (CSW) obtained from a concrete batching plant at Durable Mix, Panchor, Muar, Johor, towards alternative and sustainable practice to the soil stabilisation for road sub-base. Concrete slush is a leftover or waste from the concrete batching plant (Figure 2) that is not used in the construction site, and then it has been transferred to landfill.

This study aimed to improve the strength performance of locally available soil around Pagoh, Muar, Johor, Malaysia. This study is intended to objectively analyse the effect of different percentages of CSW (0, 3, 6, 9, and 12% to dry weight of soil) on the strength performance of locally available soil around Pagoh, Muar, Johor, Malaysia. The general index properties were observed include particle size analysis, specific gravity, plastic limit and liquid limit test. Standard proctor compaction test and California bearing ratio (CBR) test are the main geotechnical tests were conducted in this research. Therefore, besides improving road strength performance, it is expected to save the environment and promoting sustainable construction practices.

Fig. 2 - Concrete Slush Waste (CSW)

2. Materials and Methods

2.1 Materials

Two primary materials were used in this research which are soil and concrete slush sample (CSW). The soil sample used was obtained from locally available soil around Pagoh, Muar, Johor, Malaysia, which was used as a fill materials for road construction. The disturbed sample was used throughout the study and was collected by using a shovel at a depth of 0.5 m to 1 m from the ground surface. Then, the collected samples were placed into heavy duty plastic bags and transported to the laboratory. The soil samples were oven-dried at 105°C for 24 hours.

The CSW is a by-product construction material was collected from batching plant that located at Panchor, Jorak as shown in Figure 3. The CSW was then crushed manually using a rubber hammer and sieved passing through 0.475 mm size (in powder form) that was further used throughout this research

Fig. 3 - Durable Mix Concrete Batching Plant, Panchor, Muar, Johor

2.2 General Laboratory Testing Method

The present paper focused on the investigation of the performance of stabilised-soil at different percentage of CWS (0, 3, 6, 9 and 12%). Total five tests were carried out in this study, and it was divided into two parts, which are index properties test and geotechnical properties test. The index properties test includes of Hydrometer test, Atterberg limit test and specific gravity test was carried out to identify and classified the type of soil. However, the standard proctor compaction test and California bearing ratio (CBR) test were performed as the main geotechnical tests in this study to evaluate the effectiveness of CSW in enhancing the performance of local problematic soil at Pagoh, Muar, Johor. All tests were conducted as outlined in BS 1377-2:1990 [16] and Head [17].

2.2.1 Index Properties Test

Table 1 provides an overview of tests performed for index properties in this study. Particle size distribution is one of the important criteria of engineering properties that are generally associated with bearing capacity, compressibility, permeability and shear resistance. The particle size distribution in the soil is determined through the hydrometer method, which refers to the proportions by dry mass of a soil distributed over a given range of particle-size and was used in accordance with the plasticity index (PI). The Atterberg limit test was carried out to determine a crucial water content that corresponds to different soil behaviour, including liquid limit (LL) and plastic limit (PL) stages. The soil sample was oven-dry at a temperature of 105ºC and passing through a sieve of 0.425 mm. LL was determined based on a dropped cone penetration test with a standard cone of 80 g and an apex angle of 30, which assumes 20 mm penetration at LL. Whilst PL refers to that water content at which the soil sample starts to crumble when rolled into a 3 mm diameter thread. The plasticity index (PI) is the numerical difference between the liquid and the plastic limit (PI = LL – PL), representing the water content spectrum through which the soil remains plastic. The Unified Soil Classification System (USCS) and American Association of State Highway and Transportation Officials (AASHTO) were then adopted to identify the soil type, which covered the entire spectrum of fine-grained soil with widely used parameters relating to texture, soil fraction and the relationship between moisture content. Table 2 indicates soil grading by the plasticity index.

Table 1 - Outline of the index properties tests were conducted

Testing	Testing Standard	Description	Parameter determined
Hydrometer	BS 1377-2:1990 (Clause 9)	It is to measure the particle size distribution of the smallest fractions, which passes through sieve No. 200 (0.075 mm). It based on the specific gravity of the soil suspension at the center of its bulb at a specific time. The specific gravity is dependent on the concentration and dispersant agent added. In this test, the soil specimen is dispersed in water and the soil particle will settle individually. The grain sizes are determined based on sedimentation time and hydrometer cylinder in compliance with the Stoke's Law.	Particle size distribution
Atterberg limits (LL & PL)	BS 1377-2:1990 (LL – Clause 4) BS1377-2:1990 (PL – Clause 5)	LL is the consistency of moisture at which the soil transitions from solid to the liquid state. While PL has been identified as the moisture content at which the soil passes from the plastic to a solid-state, which becomes too dry to be in plastic condition and used to design road pavement thicknesses.	Liquid limit (LL) and Plastic limit (PL)
Specific gravity, G_s	BS 1377-2:1990 (Clause 8)	The pycnometer or density bottle method is the standard testing method used for determining the specific gravity of soil. It was determined based on the ratio of a soil's mass to the density of an equivalent volume of water	Specific gravity

Table 2 – Soil classification according to plasticity index [18]

Plasticity index (PI)	Degree of plasticity	Degree of cohesiveness	Soil type
0	Non-Plastic	Non-cohesive	Sand
< 7	Low Plastic	Partly cohesive	Silt
7-17	Medium plastic	Cohesive	Silty clay or clayey silt
>17	High plastic	Cohesive	Plastic clay

2.2.2 Main Test: Geotechnical Properties

a) Standard Proctor Compaction Test

Compaction is a process by which the solid particles are mechanically packed more closely together, thereby increasing the dry density [19]. It is achieved through the reduction of the air voids in the soil. At low moisture content, the soil grain is surrounded by a thin film of water, which tends to keep the grains apart even when compacted. As well as more water, up to a certain point, more air to be expelled during compaction. In the end, soil grains become as tightly packed together as they can, that is at the dry density is at its maximum. When the amount of water exceeds the required to achieve this condition, the excess water begins to push particles apart, so the dry density reduced.

In this study, the proctor compaction test was carried out by using a soil sample passing No. 4 sieve (4.75 mm) to determine the maximum dry density (MDD) at which soil can reach its optimum moisture content (OMC). Five different percentages of CSW (0, 3, 6, 9, and 12%, and 0%) by dry weight were randomly mixed with each soil sample separately, 0% is a control sample. The mixtures are initially compacting at 12% water content (based on pilot results) into a cylinder mould of 100 mm diameter and 127 mm height to 3 equal layers. Each layer receiving 27 numbers of blows from 2.5 kg weight of hammer falling from a height of 300 mm (light compaction). The process is repeated by adding 3% and continues until at least two weights of soil decreased. Then, to establish compaction curve, the relationship of moisture content and dry density was plotted. The peak point of the compaction curve was obtained from The MDD value and its corresponding moisture content as OMC. The test was carried out as outlined in BS 1377-4:1990.

b) California Bearing Ratio (CBR) Test

The CBR test is important to evaluate the strength of subgrade soil, subbase and base course material of roads and pavements. The CBR value commonly used with the empirical curves is to design the thickness of road pavement and component layers on the road. This is the most widely used in the design of flexible road pavement; more pavement thickness needed when the CBR value is low, while the pavement thickness will continuously decrease at a high CBR value.

A series of unsoaked CBR tests were conducted in this study to assess the strength performance of stabilised soil with CSW percentages of 0, 3, 6, 9 and 12%. The test was carried out in accordance with BS 1377-4:1990 (Clause 7). The soil samples were prepared based on the OMC and MDD values obtained from the compaction test. Then, the soil sample was compacted into the cylindrical mould with diameter of 150 mm and height of 127 mm using automatic compaction machine into 3 equal layers. Each layer of soil receiving 62 numbers of blows from a 2.5 kg weight hammer at a drop height of 300 mm. The load is applied to penetrate the soil surface and the penetration load values were automatically recorded by a data logger. The test was conducted at a penetration rate of 1.27 mm/min. Figure 4 shows the CBR machine used for CBR testing. Once the test is complete, approximately 5 g of soil sample was taken for moisture content determination. The graph of load against penetration is plotted. Then, the CBR value was observed at 2.5mm and 5mm penetration and expressed as a percentage of the standard forces of 13.2kN and 5kN, respectively. The same procedure is repeated to the different percentages of CSW. For each CSW percentage, a total of 3 measurements were performed to get the average CBR value.

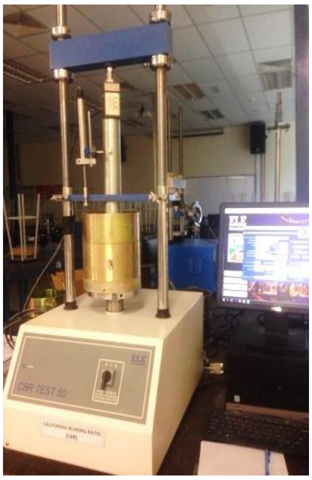

Fig. 4 - CBR machine

3. Results and Analysis

3.1 Index Properties of Soil

Table 3 summarises the index properties evaluated from this study and used to identify and classify the soil type. Atterberg Limit test is done to determine the PI based on PL and LL value. The results show that the LL and PL of the soil used throughout this study are 57.2% and 22.61%, respectively. Thus, for the plasticity index (PI) data recorded as 34.59%. Based on plasticity index (refer Table 2), the soil is classified as a high plasticity clay. The specific gravity of soil used is 2.56, which was classified as organic soil by Roy and Bhalla [18], and Bowles [20].

Hydrometer test are done to determine the particle size distributions of the soil sample in accordance with standard procedures outlined in BS 1377:1990. The fines percentage passing through the No. 200 sieve found in soil sample is 45.2 %. The soil used can be categorised under CL (sandy lean clay) based on the USCS system, which corresponds to particle size and moisture content [20]. According to AASHTO, the soil is classified as A-7-6, which is clayey soil [21]. Such kind of soil is not ideal for construction purposes, therefore, it must be stable to make it desirable.

Table 3 - Index properties of locally available red soil at Pagoh, Muar, Johor, Malaysia

Index properties	Value
Liquid limit, LL (%)	57.20
Plastic limit, PL (%)	22.61
Plasticity index, PI (%)	34.59
Fines percentages (%)	45.20
Specific gravity	2.56

3.2 Compaction Characteristics

The standard proctor compaction test was done to obtain OMC and MDD relationship for the various concrete slush waste (CSW) mixtures (0, 3, 6, 9 and 12 %). Figure 5 shows the relationship between dry density and moisture content at different SCW obtained from the compaction test. The results obtained show that the OMC of the virgin soil sample is 13.8%, while the OMC of stabilised soil with 3%, 6%, 9% and 12% of CSW are 15.96%, 16.21%, 18.32%, 18.0%, respectively. Nevertheless, the MDD value of the virgin soil sample is 1.82 g/cm^3 while for stabilised soil are 1.76 g/cm^3, 1.78 g/cm^3, 1.76 g/cm^3 and 1.77 g/cm^3, respectively. The increase in OMC with a higher slush content could be due to the extra water required for the hydration of the slush to take place. However, the rise in the CSW percentage does not show a significant difference in MDD value. The result obtained is used to prepare a sample for the CBR test, and it has been useful in the stability of soil, since the compacted soil in the field is regulated by the value of OMC.

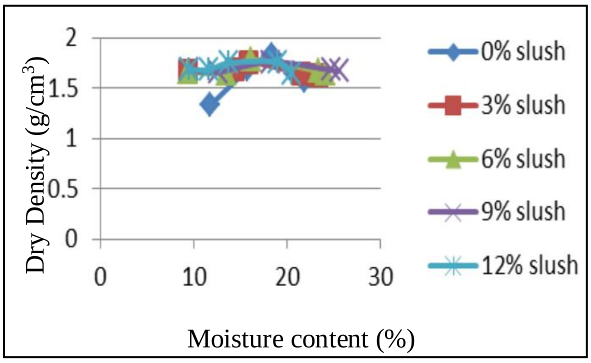

Fig. 5 - Relationship of dry density and moisture content

3.3 California Bearing Ratio (CBR) Characteristics

The effect of CSW on stabilised-soil strength was assessed primarily through the CBR characteristic. The CBR test was performed in unsoaked conditions by measuring the pressure needed to penetrate a soil sample with a plunger. The results then was used to determine load bearing capacity of the soil. The CBR sample was prepared by compacting the soil using an automatic compaction machine for 62 blows for each equal three layers with the addition of water content obtained from the compaction test.

The relationship of plunger load and penetration at different CSW percentage is plotted as in Figure 6. The CBR values are determined for the load which corresponds to the 2.5 mm and 5.0 mm penetration as summarised in Table 4, and generally the higher value have been adopted as CBR value. The results show that the CBR values at 2.5mm penetration are found to be higher than those at 5.0mm penetration.

Figure 7 further shows the effect of different percentages of CSW (3, 6, 9, and 12 %) on CBR value of stabilised-soil. The shape of the curve shows that the CBR value has increased by 9.70%, 22.98%, 32.34%, 40.44%, and 45.44% with the rise in CSW percentages of 0%, 3%, 6%, 9% and 12%, respectively. Furthermore, it has also been shown that the CBR value at 6% (32.34%) of the CSW have achieved the standard requirement for road sub-base which is 30% [22]. The findings revealed that the CBR value achieved the highest value at 1.2% of CSW content. From this, it can be concluded that strength of stabilise soil increases with increasing percentage of CSW due to cement content from the slush that composed of lime, silica and alumina which provides special characteristics in soil stabilisation [8].

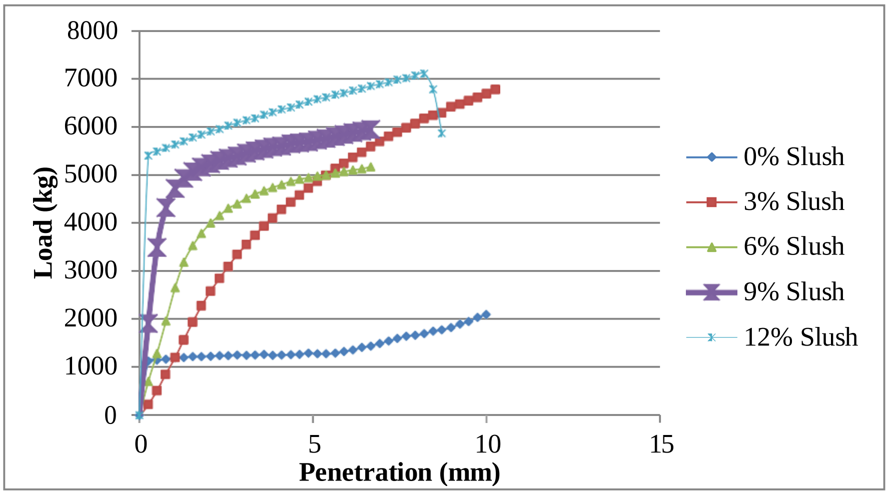

Fig. 6 - Load and penetration curve at different CSW percentages

Table 4 – CBR value at 2.5 mm and 5.0 mm penetration

CSW ratio (%)	CBR at 2.5 mm penetration (%)	CBR at 5.0 mm penetration (%)
0	9.70	8.11
3	22.98	23.99
6	32.34	24.81
9	40.44	28.56
12	45.44	32.77

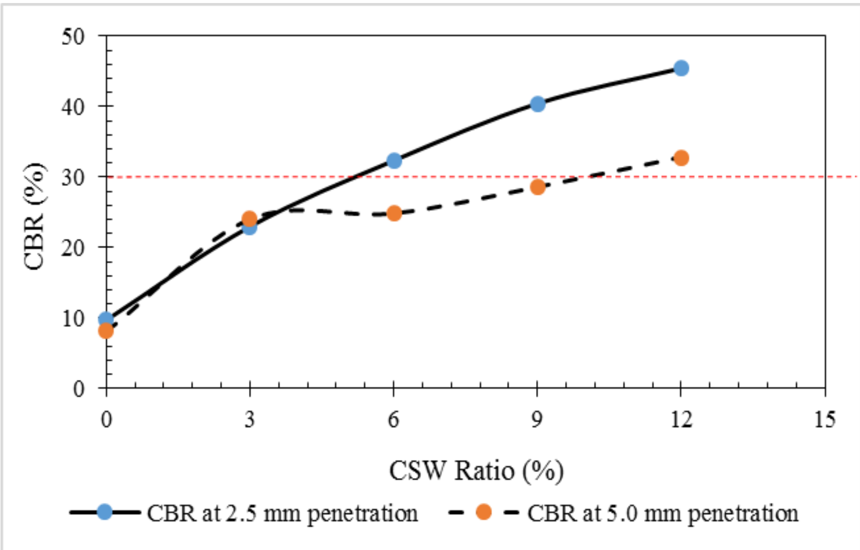

Fig. 7 - Effect of different CSW percentages on CBR value at 2.5mm and5 mm penetration

4. Conclusion

The soil sample used in this study can be graded as high plasticity clay soil with LL more than 50%, PI more than 30 %, a specific gravity of 2.56, and 45.2% fines particles passing through sieve No. 200. Such soil requires special treatment to meet the performance desired. Based on the results obtained, it can be concluded that concrete slush waste (CSW) has the potential to modify the engineering behaviour of high plasticity clay soil and make it suitable for road sub-base construction. The CBR value significantly increases from 9.70% to 45.44%, with the rise in CSW percentages from 0% to 12%. The CBR values of the stabilised soil with 6% of CSW and above are found to meet the requirement for road sub-base material which is 30%. The findings showed that the CBR value achieved the highest value at 1.2% of CSW content.

Therefore, the use of concrete slush waste in soil stabilisation is an innovative idea due to a few reasons, including being able to absorb water, availability, simple production process, and sustainable practice, good for the environment as well as an efficient way to reduce costs. Besides, the use of concrete slush waste will also promote environmental incentives to provide a way to recycle large quantities for engineering purposes.

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