Improvement of crushed rock by polymer and portland cement on California Bearing Ratio (CBR) under soaked condition

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ABSTRACT

The pavement consists of surface course built on the top followed by base, subbase, and subgrade, respectively. The high stresses occur at the top layer, which is placed by the expensive material with high quality, while cheaper material with low quality is placed in the lower layer, respectively. Crushed rock is normally applied as the base material, which is required to support the high stress transmission. The soil improvement techniques have become one alternative to apply for increasing the soil strength. The one technique has been wildly adopted, is called "soil cement". On the other hand, the soil cement road is easily to damage by heavy raining and flooding, due to brittle crack behavior in Portland cement property. Consequently, polymer has high elastic modulus, is precious to solve the brittle failure problem. This paper examines the effect of concurrent use of liquid polymer and Portland cement on crushed rock as reinforced pavement base material. The strength of polymer-treated crushed rock (treated crushed rock) and ordinary crushed rock (untreated crushed rock) were characterized and compared. In strength analysis, the California bearing ratios (CBR) of untreated and treated crushed rock were determined under soaked condition to simulate post-flood pavement damage. As a result, it was found that the CBR value of the treated crushed rock has higher than the CBR values of the untreated crushed rock (approximately two times).

Keywords: Polymer; CBR; Base; Pavement; Crushed rock

1 INTRODUCTION

There are many soil improvement techniques to enhance the engineering properties (e.g. strength, stiffness, durability and bearing capacity etc.) of natural aggregates, including fine grained soil and coarse grained soil (crushed rock). There are two conventional techniques: mechanical and chemical. The mechanical technique uses static or dynamic compaction to increase soil density and bearing capacity. The chemical method mixes the natural aggregate with traditional (e.g., cement, bitumen, fly ash) or nontraditional stabilizing materials)e.g., resins, ionic, polymer(.

Portland cement mixes the natural aggregate (i.e., soil cement) was first used in 1935 to improve soil strength for highway construction)Mitchell et al., 1959(. The strength of soil cement, including fine-grained soil and coarse-grained soil, was assessed by California bearing ratio and unconfined compressive strength (Naeini et al., 2012; Saha and Pal, 2013; and Esklsar, 2015(.

Garber et al. (2011) experimented using a mixture of crushed rock, cement, and water (i.e., cement treated base (CTB)) for pavement structure by varying cement content between 3%-8% by aggregate weight, depending on the required strength. According to Austroads (2010), cement contents of 4-5% by CTB aggregate weight resulted in a modulus of 500 MPa - 5000 MPa. Thus, lower cement contents are suitable for coarse grained soil and high cement contents for fine grained soil. Increase in CTB cement content contributed to stiff base material and susceptibility to brittleness

In addition to Portland cement, high-elastic-modulus polymer was incorporated in soil to mitigate the brittle crack (Wang et al., 2016(. The polymer improved the flexibility, durability, and water proofing of soil cement)Mirzababaei et al., 2017; and Menhosh et al., 2018).

Therefore, the objective of this paper is to examine the concurrent use of liquid polymer and Portland cement to strengthen crushed rock as reinforced pavement base material. In the study, the strength of polymer-treated crushed rock (treated crushed rock) and ordinary crushed rock (untreated crushed rock) were characterized and compared. In the analysis, the California bearing ratios of untreated and treated crushed rock were determined under soaked conditions to simulate the post-flood pavement damage.

2 POLYMER

The experimental liquid polymer was vinyl copolymer emulsion (Soiltac, Soilworks LLC) of milky white color, pH 4.5-6.0, and a specific gravity of 1.05-1.10 (Table 1). The polymer was first diluted (10.5 cc/390 g tap water) and mixed with Portland cement (Type 1, TPI) and crushed rock for the treated crushed rock. The ratio of diluted polymer to Portland cement was 5 g:100 g, and that of cement to crushed rock was 3.5 g:100 g.

Table 1. Properties of polymer.

Property	Characteristics/Value
Physical State	Liquid polymer
Colour	Milky White color
Component	Vinyl Copolymer Emulsion
pH	4.5-6.0
specific gravity	1.05 to 1.10.

3 CRUSHED ROCK PROPERTIES

The basic properties of untreated crushed rock were classified by laboratory testing, including Atterberg's limit test and sieve analysis test. The laboratory testing base on the standard of American Society for Testing and Material)ASTM(, which is similar to the standard of American Association of State Highway and Transportation Officials)AASHTO(.

3.1 Atterberg's limit test

The liquid limit, plastic limit, and plasticity index of untreated crushed rock were characterized using Atterberg's limits test in accordance with ASTM D4318. The relationship between the liquid limit (LL), plastic limit (PL), and plasticity index (PI) can be expressed as

$$PI = LL - PL \tag{1}$$

In this research, the initial moisture content was 17.46%. The moisture content was further increased and varied between 17.85%, 18.14%, 18.73%, and 19.23%, with the corresponding number of blows of 32, 26, 18, and 13 blows. The LL of untreated crushed rock corresponding to 25 blows was 18.22%.

In PL analysis, the experiments were carried out in triplicate. The average PL of untreated crushed rock was 13.72%. The PI of untreated crushed rock was 4.50%, where PI = LL - PL.

3.2 Sieve analysis test

Sieve analysis was carried out to determine the distribution of particle sizes of untreated crushed rock in accordance with ASTM D-421.

Figure 1 illustrates the grain size distribution of untreated crushed rock as a function of the percentage of passing by weight and the size of particle by diameter. Specifically, the untreated crushed rock passing sieve no. 2", 1", 3/8", #4, #10, #40, and #200

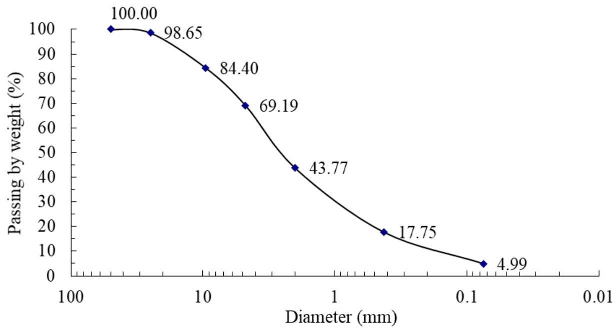

Fig. 1. Grain size distribution curve of ordinary crushed rock.

were 100%, 98.65%, 84.40%, 69.19%, 43.77%, 17.75%, and 4.99%, respectively. In the figure, the 10% (D_{10}), 30% (D_{30}), and 60% (D_{60}) passing by weight were 0.18 mm, 1.00 mm, and 3.50 mm. The coefficient of uniformity)C_u(and coefficient of gradation)C_c(are a function of D_{10}, D_{30}, and D_{60} as:

$$C_u = D_{60}/D_{10} \tag{2}$$

$$C_c = (D_{30})^2/(D_{10}xD_{60}) \tag{3}$$

where C_u> 4 and $C_c \approx$ 1-3 denote well-graded gravel, C_u> 6 and $C_c \approx$ 1-3 well-graded sand, and $C_u \approx$ 1 poor-graded sand. In this research, C_u and C_c of untreated crushed rock were 19.44 and 1.59.

According to the unified soil classification system)USCS(, the particles of untreated crushed rock passing sieve #200 and #4 were 4.99% (<50%) and 69.19% (>50%), respectively, indicating that the untreated crushed rock was sand. Given C_u = 19.44 and C_c = 1.59, the experimental untreated crushed rock was of well-graded sand (C_u> 6 and $C_c \approx$ 1-3).

According to the American Association of State Highway and Transportation Officials (AASHTO), the maximum percent passing sieve #10, #40, and #200 are 50%, 30%, and 15%. In this research, the percent passing sieve #10, #40, and #200 of the untreated crushed rock were 43.77%, 17.75%, and 4.99%, which is classified as A-1-a. The untreated crushed rock is thus of high quality as pavement base material.

4 EXPERIMENTAL PROCEDURES

4.1 Testing conditions

To understand the effect of concurrent use of liquid polymer and Portland cement on crushed rock as reinforced pavement base material, the specimens were prepared and tested by comparing 2 different cases as follows:1) ordinary crushed rock, called untreated crushed rock, and 2) ordinary crushed rock mixed with Portland cement (3.5% of crushed rock by weight) and polymer (5% of Poland cement by weight), called treated crushed rock. This proportion is used on the standard specification of department of rural roads.

4.2 Compaction test

The modified proctor compaction (ASTM D1557) is a function of the dry density and water content of a material. The maximum dry density)$\gamma_{d,\ max}$(and optimal water content (OWC) of untreated and treated crushed rock were determined. The OWC was used for analysis of California bearing ratio (CBR).

In the preparation of untreated and treated crushed rock samples, tap water of arbitrary amounts (i.e., five variations each for untreated and treated crushed rock) was added to the crushed rock. The water contents of untreated crushed rock were 1.01%, 2.48%, 4.90%, 7.01%, and 8.89%, and the corresponding dry densities were 2.17 t/m^3, 2.20 t/m^3, 2.33 t/m^3, 2.26 t/m^3, and 2.20 t/m^3. Meanwhile, those of treated crushed rock were 1.19%, 2.77%, 4.90%, 7.55%, and 10.20%, and the dry densities were 2.17 t/m^3, 2.21 t/m^3, 2.32 t/m^3, 2.27 t/m^3 and, 2.16 t/m^3, respectively.

Figures 2-3 respectively illustrate the compaction curves of untreated and treated crushed rock as a function of water content and dry density, whose peak represents the maximum dry density at the optimal water content. Specifically, $\gamma_{d,\ max}$ of untreated and treated crushed rock were 2.33 t/m^3 (OWC = 5.10%) and 2.32 t/m^3)OWC = 5.20%).

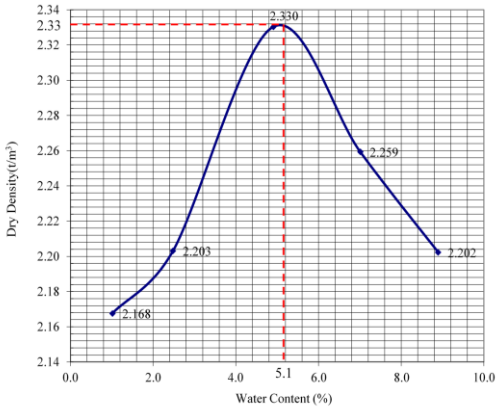

Fig. 2. Compaction result of untreated crushed rock.

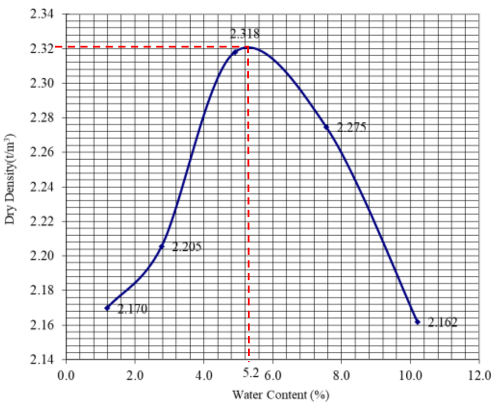

Fig. 3. Compaction result of treated crushed rock.

4.3 California bearing ratio test

California bearing ratio (CBR) describes the strength of a material in relation to the bearing capacity of well-graded crushed rock whose CBR is 100% at the maximum dry density. The bearing capacity of a material is governed by water content, dry density, and material type. In this research, the CBR of untreated and treated crushed rock is subject to ASTM D1883.

In CBR analysis, the untreated and treated crushed rock passing sieve#4 were mixed with tap water (5.10% and 5.20% OWC, respectively). The rocks were prepared with three molds (compacted 10, 25, and 56 blows in each layer) each for untreated and treated crushed rock.

In penetration testing, the penetration carried out at a rate of 1.27 mm/min. The load measurements corresponding to the following deformation were taken: 0.64 mm, 1.27 mm, 1.91 mm, 2.54 mm, 3.18 mm, 3.81 mm, 4.45 mm, 5.08 mm, 7.62 mm, 10.16 mm, and 12.70 mm.

The swelling behavior of untreated and treated crushed rock were characterized under soaked condition to simulate flooding whereby the crushed rock samples (in the mold) loaded with 10-pound surcharge weight were submerged for 96 h prior to penetration test. The submersion enabled free access of water throughout the crushed rock samples. The swelling after 96h-submersion was calculated by:

$$\%\text{swell} = \frac{\text{Sample extension during soaking}\left(\text{in.}\right)}{4.584\left(\text{in.}\right)} \times 100 \quad (4)$$

The load and deformation at 0.2-inch penetration depth under unsoaked and soaked conditions were converted into CBR of untreated and treated crushed rock. The resulting CBR were then compared against that of standard crushed rock at 0.2-inch penetration depth (i.e., 1500 psi). The CBR can thus be expressed as

$$\text{CBR}\ \left(\%\right) = \frac{\text{Test unit load}}{\text{Standard unit load}} \text{ x } 100 \quad (5)$$

5 RESULTS

Figure 4 compares the CBR of untreated crushed rock under soaked and unsoaked conditions. Under the unsoaked condition, the CBR at $\gamma_{d,max}$ of 2.03 t/m^3 (10 blows), 2.15 t/m^3 (25 blows), and 2.29 t/m^3 (56 blows) were 75.74%, 119.46%, and 218.58%, respectively. Under the soaked condition, the CBR at $\gamma_{d,max}$ of 2.12 t/m^3 (10 blows), 2.23 t/m^3 (25 blows), and 2.35 t/m^3 (56 blows) were 104.46%, 152.50% and 157.84%.

In Figure 4, the unsoaked CBR of untreated and treated crushed rock were positively correlated to compaction blows, suggesting that compaction blows had minimal effect on the CBR.

In practice, the achievable maximum dry density, given any OWC, is 95%. Thus, $\gamma_{d,max}$ of untreated crushed rock was 2.215 t/m^3 (i.e., 95% of $\gamma_{d,max}$ of 56 modified compaction blows). The CBR of unsoaked and soaked untreated crushed rock, given $\gamma_{d,max}$ of

2.215 t/m^3, were 172.87% and 135.21%, respectively. Specifically, the CBR of untreated crushed rock decreased once submerged in water for an extended time period (96 h). This explains the post-flood damage to untreated pavement.

Figure 5 compares the CBR of untreated and treated crushed rock under soaked condition (96 h). The soaked CBR of untreated crushed rock of 10, 25, and 56 compaction blows were 104.46%, 152.50%, and 157.84; and 292.80%, 297.38% and 328.64% for the corresponding treated crushed rock. The soaked CBR of treated crushed rock was approximately twice as high as that of untreated crushed rock.

Table 2 tabulates the CBR of untreated and treated crushed rock under soaked condition, given 10, 25, and 56 blows. The swelling index of untreated and treated crushed rock under soaked condition, and the swelling indices were 0% for untreated and treated samples. This indicated that liquid polymer and Poland cement had no impact on the crushed rock when submerged under water.

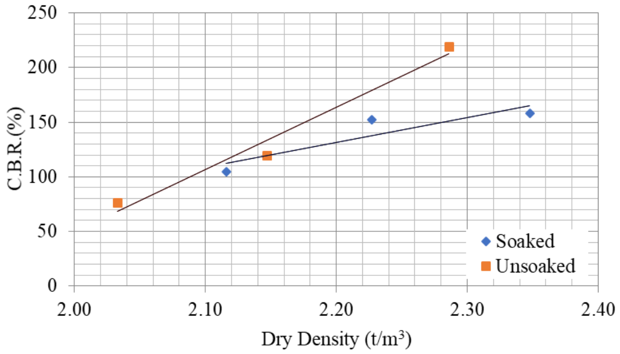

Fig. 4. CBR of untreated crushed rock.

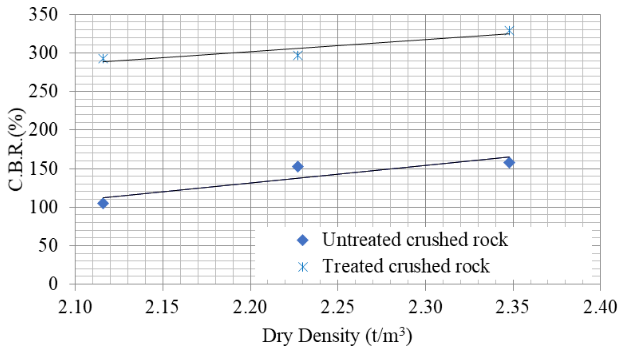

Fig. 5. Comparison the CBR under soaked condition.

Table 2. CBR of untreated and treated crushed rock under soaked condition.

Density (g/cc.)	C.B.R. (%)			
	Untreated crushed rock	Swell (%)	Treated crushed rock	Swell (%)
2.12	104.46	0.00	292.80	0.00
2.23	152.50	0.00	297.38	0.00
2.35	157.84	0.00	328.64	0.00

6 CONCLUSIONS

The effect of liquid polymer and Portland cement to strengthen crushed rock as reinforced pavement base material. The strength of polymer-treated crushed rock (treated crushed rock) was assessed in relation to ordinary crushed rock (untreated crushed rock) based on the California bearing ratio (CBR) under soaked condition to simulate the post-flood pavement damage. The findings are as follows:

1. The CBR of untreated and treated crushed rock were positively correlated with dry density.
2. The CBR of untreated crushed rock decreased when submerged under water.
3. Under the soaked condition, the CBR of treated crushed rock was twice as high as that of untreated crushed rock.

Hence, the liquid polymer and Portland cement can apply to improve the strength of crushed rock and mitigate the post-flood pavement damage.

ACKNOWLEDGEMENTS

This research was supported by King Mongkut's Institute of Technology Ladkrabang Research Fund (KREF016105).

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