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PROPERTIES AND PERFORMANCES OF SOIL CEMENT MODIFIED WITH CONCENTRATED PARA-RUBBER

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ABSTRACT: Due to the slump of the price of Para-rubber, the Department of Highways of Thailand has adopted the rubber to be used in the quality improvement of cement stabilized materials. Hence, this research aims to study the changes of properties of soil cement modified with concentrated Para-rubber. Lateritic soils were mixed with cement, at the ratio of 1, 3 and 5%, and Para-rubber, at the ratio of 1 and 2% of dry soil weight. The shear wave velocity (*Vs*), unconfined compressive strength (*UCS*), strain at failure, indirect tensile strength (*IDT*), resilient modulus (*MR*), fatigue resistance (*FR*) and soil permeability (*k*) were tested after 7 days of curing. The results indicated that *UCS* increased with the increase of cement ratio but tended to decrease with the increase of Para-rubber which were consistent with the results of *Vs*. For the performance tests, *IDT* and *MR* tended to decrease while *FR* and *k* tended to increase with the increase of Para-rubber. It was expected that Para-rubber affected the compaction quality and, probably, the creation of a hydration reaction. Conclusively, the addition of cement increased the brittleness of the material resulting in higher strength. On the other hand, the addition of Para-rubber increased the ductility resulting in lower strength but higher deformation and higher fatigue crack resistance.

Keywords: Para-rubber, Cement, Strength, Fatigue, Performance

1. INTRODUCTION

The Department of Highways of Thailand (DOH) has been using cement to improve road structure quality for a long time. By mixing cement with soil and water, the compressive strength of soil cement (SC) is increased due to the hydration reaction resulting in its ability to carry higher load [1-4]. The polymer additive has been extensively used for improving the strength, stiffness and durability of pavement materials for more than a decade. Occasionally, the polymer was added into the cement stabilized pavement layers to enhance the elastic behavior of strong-but-brittle material [5]. Reviewing on the past research indicates that, most of the polymers employed for soil stabilization are industrial made or synthetic [6-8]; limited number of previous research focused on the applications of natural polymer.

However, due to the slump of the price of Para-rubber, DOH has been assigned to use Para-rubber in their missions with the intention to increase the consumption of Para-rubber in the country. One of them is the use of Para-rubber to improve the properties of SC layer. With the purpose of doing so, the study of the effects of mixing high amount of Para-rubber into SC is preferable because it can enhance the demand within the country.

The effect of natural rubber on the compressive strength of construction materials has been mainly emphasized by the previous studies. The compressive strength trended to decrease with an increasing of rubber content [9-12], though some indicated an increase of compressive strength when using small amount of rubber content [13-15]. Nonetheless, even an addition of natural rubber seemed to lessen the compressive strength of materials, it could increase the ductility, skid resistance and durability of the soil cement [12,16,17] and increase the resilient modulus of asphaltic concrete [18]. Moreover, in order to use soil cement as a road base course, the repetitive load under traffic condition could significantly induces fatigue crack due to its brittleness which could shorten the service life of the material. Expecting that an addition of Para-rubber which is an elastic material could enhance the fatigue resistance of the material due to the increase in its ductility leading to a longer service life compared to the conventional soil cement layer. However, the study of such effect has yet to be widely examined. Understanding the potential and the behavior of using Para-rubber for soil cement modification could lead to the most optimum design criteria and maintenance guiding to a more economical and sustainable pavement material construction in the future.

With the reasons mentioned above, the objectives of this study are first to study the effects of Para-rubber on behavior, properties and performances of soil cement modified with concentrated Para-rubber (SCP) and second to study the potential of using high amount of Para-rubber, 60% of dry rubber content (DRC), to improve the soil cement base. The tests comprise of shear wave velocity (*Vs*), unconfined compressive strength (*UCS*), strain at failure, indirect tensile strength (*IDT*), resilient modulus (*MR*), fatigue resistance (*FR*) and soil permeability (*k*).

2. RESEARCH SIGNIFICANCE

The use of Para-rubber to improve the properties of soil cement for road construction is relatively new. This study introduces the effect of using high amount of Para-rubber on the properties of soil cement. The finding is significant as it demonstrated that the soil cement modified with Para-rubber could be benefited from higher ductility and higher fatigue crack resistance which could direct to a more economical and sustainable road design and construction.

3. BASIC PROPERTIES OF MATERIALS

The soils used in this study were lateritic soils from 2 sources, Chainat province and Chonburi province. The soils were tested for their basic properties according to [19-24]. The results of the basic properties and the soil classifications are shown in Table 1. The grain size distributions are shown in Fig. 1. The results showed that the lateritic soils from both sources met the requirements of [25, 26]. However, the lateritic soil from Chainat was a more suitable material for road structure as it has lower plasticity, lower fine content, higher compacted dry density, higher California bearing ratio (CBR) value, and lower percent loss by Los Angeles abrasion compared to the lateritic soil from Chonburi.

The cement used was Portland cement type 1. The Para-rubber latex used was concentrated latex type HA (High Ammonia) that contains no less than 60% of DRC. Nonionic surfactant NP9 (Nonylphenol Ethoxylate 9 MOLES) was also used to help preventing the rubber particles from clumping before mixing with the aggregates.

4. METHODOLOGY

4.1 Shear Wave Velocity and Unconfined Compressive Strength Determinations

4.1.1 Sample preparation for shear wave velocity and unconfined compressive strength determinations

Samples from both sources were compacted with modified Proctor test in the mold with an inner diameter of 101.6 mm and a height of 116.43 mm by considering the use of cement content of 1, 3 and 5% and the use of Para-rubber of 0 (SC), 1 and 2% of dry soil weight. The surfactant used was 5% of cement weight. To be noted that the amount of added water for compaction was calculated from the optimum water content subtracted the amount of Para-rubber and surfactant. Five samples per mixture ratio were prepared to study the effect of cement and Para-rubber contents on *Vs* and *UCS* as shown in Table 2. After the compaction, the samples were wrapped in a plastic sheet and cured for 7 days. Then, the samples were immersed in water for 2 hours before conducting the free-free resonance (FFR) test and then *UCS* test.

Table 1 Basic properties of lateritic soils

Basic properties	Chainat	Chonburi
Liquid Limit	Non-Plastic	26.00
Plasticity Index	Non-Plastic	9.51
Maximum Dry Density (kN/m^3)	22.86	20.40
Optimum Water Content (%)	5.30	10.00
Percent Loss (%)	39.14	49.64
CBR (%)	46.2	14.4
USCS*	SM	SC
AASHTO**	A-1-b	A-2-4

*Unified Soil Classification System
**American Association of State Highway and Transportation

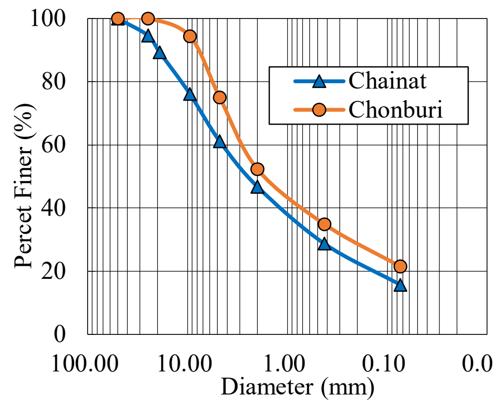

Fig. 1 Grain size distribution curves of lateritic soils from Chainat and Chonburi

Table 2 Number of samples for FFR and UCS tests

Cement (% by weight)	Para-rubber (% by weight)	Chainat (Sample)	Chonburi (Sample)
1	0	5	5
1	1	5	5
1	2	5	5
3	0	5	5
3	1	5	5
3	2	5	5
5	0	5	5
5	1	5	5
5	2	5	5

4.1.2 Free-free resonance (FFR) test

FFR test is a low strain, undisturbed, dynamic test that is simple, reliable and has been widely used to determine the resonant frequency and shear wave velocity of materials [27-30]. In this study, the sample was placed on the sponge to create a free-boundary condition. An accelerometer was attached horizontally at the side of one end, perpendicularly to the long side, of the sample. Shear waves were generated by vertically tapping the sample at the side of the other end, perpendicularly to the orientation of the accelerometer, using a small impact hammer as shown in Fig. 2a. The resonant, maximum peak amplitude, frequency was recorded, then shear wave velocity was analyzed using the following equation,

$$Vs = f\lambda = 2fL \tag{1}$$

where f is resonant frequency, λ is wavelength and L is sample length.

4.1.3 Unconfined compressive strength (UCS) test

After the completion of FFR test, the same sample was put into the universal testing machine (UTM) for *UCS* test according to [31]. The shearing rate was 2 mm/min. The *UCS* and strain at failure of the samples were recorded for further analysis. An example of the test is illustrated in Fig. 2b.

4.2 Laboratory Performance Tests

4.2.1 Admixture design and sample preparation for laboratory performance tests

After the *UCS*-cement content analysis, the mixing ratio was determined for laboratory performance tests, including *IDT*, *MR*, *FR*, *k*. The designed cement content, normally, is determined to satisfy the required *UCS*, 1724 kPa after 7 days of curing time, according to [25], of SC. However, in this study, the amount of cement content was depended on the 125% of normal designed strength to avoid the potential loss of performance during the field construction in the future. The targeted *UCS* then became 2155 kPa instead. This criterion was applied for the soils from both sources, Chainat and Chonburi.

Three samples of SC and 3 samples of SCP from 2 lateritic sources, a total of 12 samples, were used for each test to study the performance of these materials. The soils were compacted and cured for 7 days before the tests. Details of each test are mentioned in the following topics.

4.2.2 Indirect tensile strength (IDT) test

IDT tests were performed in accordance with [32]. Samples were compacted, following a modified compaction, to a diameter of 100 mm and a height of 50 mm. The sample was arranged for testing, as shown in Fig. 2c, and was pressed until failure using a pressing rate of 50 ± 5 mm/min. The maximum force at failure (P, in N) was recorded. The *IDT* (in kPa), then, was calculated using Eq. (2)

$$IDT = \frac{2,000 \times P}{\pi \times T \times D} \tag{2}$$

where T is the height of the tested sample (in mm), and D is the diameter of the tested sample (in mm).

4.2.3 Resilient modulus (MR) test

MR tests were conducted in accordance with [33]. The size of the samples and the apparatus were as same as the *IDT* tests. To measure *MR*, the sample was subjected to 5 cycles of constant load repetitions, each cycle was subjected to a Haversine force for 0.1 s and was allowed to recover for 0.9 s before the second cycle began. The standard recommends that the optimum loading force in the test should be no more than 20% of the *IDT* measured from the same mixture to ensure that the material still responds elastically in every cycle of repetitions. The lateral swelling of the sample was also measured with Linear Variable Differential Transformer (LVDT). After the sample had been subjected to 5 repeated load cycles, the resilient modulus was calculated based on the repetitive force and lateral swelling of the sample according to the equation and procedure specified in the standard.

4.2.4 Fatigue resistance (FR) test

FR, or also called fatigue life, tests were performed according to [34]. *FR* is a value that indicates the strength of a material against repetitive loads, typically represents as the number of cycles that cause the failure of the sample. *FR* tests also use the same apparatus and sample size as the *IDT* tests. The tested sample was subjected to constant repetition of force until the specimen underwent rupture and failure. Coincide to the *MR* test, the sample was subjected to a Haversine force for 0.1 s and was allowed to recover for 0.9 s. In this study, the tested sample was subjected to constant repetition loads, which equaled to 30-40% and 60-70% of *IDT* for soil samples from Chainat and Chonburi, respectively, until failure. Number of cycles to failure was recorded and used to compare the *FR* of materials.

4.2.5 Soil permeability (k) test

K tests were carried out by constant head tests in accordance with [35]. The tested soil was compacted, following the mix design, in the molds with a dimeter of 101.6 mm and a height of 116.43 mm. The amount of water over the measured time was recorded, then the *k* of each sample was calculated. Examples of *k* tests are shown in Fig. 2d.

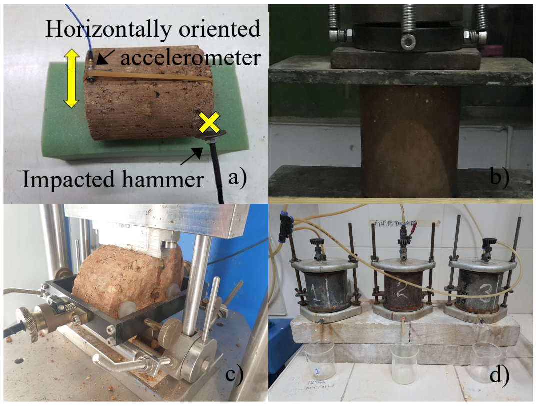

Fig. 2 Examples of (a) free-free resonance test (b) unconfined compressive strength test (c) indirect tensile strength, resilient modulus and fatigue resistance tests (d) soil permeability test

5. ANALYSIS AND TEST RESULTS

5.1 Effect of Cement and Para-rubber Contents on Shear Wave Velocity

The effect of cement and Para-rubber contents on *Vs* of SC and SCP from Chainat and Chonburi are shown in Fig. 3 and Fig. 4, respectively. It was found out that *Vs* increased with the increasing of the cement content which agreed well with [36, 37]. However, once Para-rubber was added into the mixture, *Vs* tended to decrease with an increasing of Para-rubber content instead. This could be that Para-rubber affected the compaction quality and only partially bound the soil particles, as shown in Fig. 5, resulting in higher void ratio. The amount of water replaced by the Para-rubber could also affect the cement hydration reaction, still, the microstructure analysis is required for further investigation.

5.2 Effect of Cement and Para-rubber Contents on the Unconfined Compressive Strength

The effect of cement content and Para-rubber contents on *UCS* of SC and SCP from Chainat and Chonburi are shown in Fig. 6 and Fig. 7, respectively. The results presented that at the same amount of Para-rubber, the *UCS* of all materials increases as the cement content increases, which was consistent with [38-41] and the results of FFR tests. The results also showed that at the same amount of cement content, the SC and SCP from Chainat had higher *UCS* than the SC and SCP from Chonburi which could be due to the soil basic properties.

In a similar way to *Vs*, when considering the samples that had the same amount of cement content, it was found out that the addition of Para-rubber into the mixture tended to lower *UCS* which agreed well with [42]. The loss of *UCS* could also come from the poorer compaction quality and, probably, the hydration reaction generation. It is worth noting that the amount of Para-rubber had a greater impact on strength of SCP from Chainat than Chonburi. Expecting that the soil from Chainat is non-plastic while the soil from Chonburi has higher plasticity, resulting in a higher cohesion between soil particles.

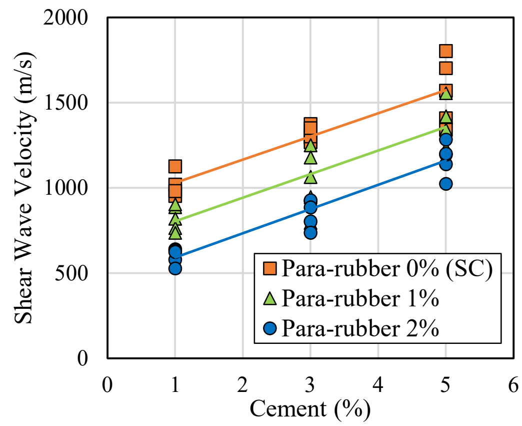

Fig. 3 *Vs* of treated soils from Chainat

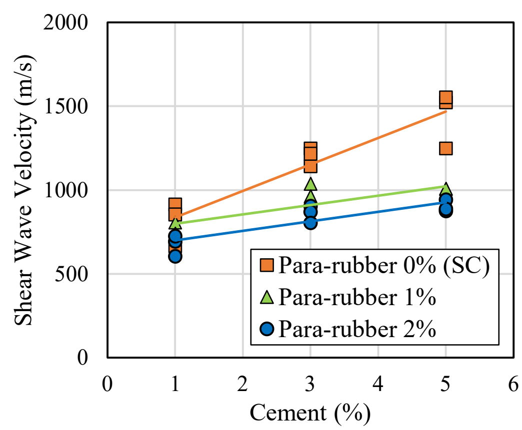

Fig. 4 *Vs* of treated soils from Chonburi

Fig. 5 Bond of Para-rubber of SCP.

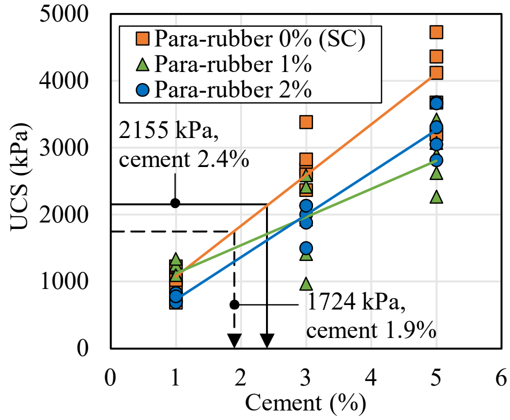

Fig. 6 *UCS* of treated soils from Chainat

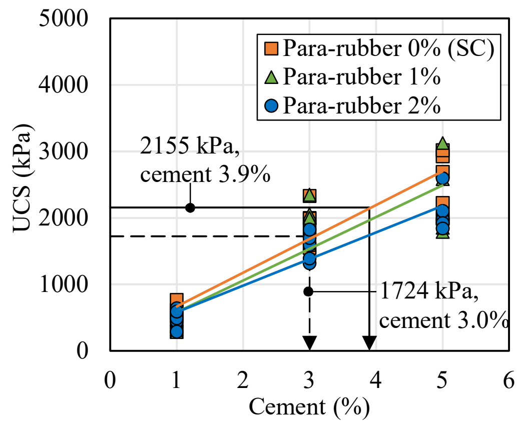

Fig. 7 *UCS* of treated soils from Chonburi

5.3 Effect of Cement and Para-rubber Contents on Strain at Failure

The strain at failure also measured from the *UCS* tests as shown in Fig. 8 and Fig. 9 for the samples from Chainat and Chonburi, respectively. The results showed that the strain decreased with the increasing of cement content suggesting that cement tended to increase the brittleness of the samples. Considering at the low amount of cement content, the samples from Chonburi had slightly higher strain than the samples from Chainat due to the higher plasticity of the soil from Chonburi. However, when considering at the high amount of cement content, there was not much different between 2 material sources as the hydration reaction may govern their behaviors. Though, the microstructure analysis is preferred.

When Para-rubber was added into the mixture, it was found that the strain at failure increased, the change was clearly seen for the addition of 2% of Para-rubber indicating that Para-rubber tended to increase the ductility of the samples [12, 15]. This could be the consequence of the high flexibility of Para-rubber. An addition of 1% of Para-rubber, however, provided slightly change on the strain at failure, expecting that the rubber created interparticle bonds only at some portions of the samples. The microstructure analysis is, again, preferred to confirm the notion.

5.4 The Admixture Ratio for Laboratory Performance Tests

The results of *UCS* of SC were used to determine the most appropriate admixture ratio for the laboratory performance tests as shown in Fig. 6 and Fig. 7. For the soil from Chainat, the soil required cement content of only 1.9% of dry soil weight to satisfy the required *UCS*, 1724 kPa after 7 days of curing time. On the other hand, the soil from Chonburi required higher cement content, 3.0% of dry soil weight to satisfy the same required *UCS*. Though, due to the reason mentioned prior, the target designed strength in this study was higher than the minimum requirement, at 2155 kPa. Hence, the optimum cement content for the soils from Chainat and Chonburi became 2.4% and 3.9% of dry soil weight, respectively.

The amount of Para-rubber used for the performance test was selected at 2% of dry soil weight for both sources as it tended to increase the ductility of the samples and, also, to satisfy the objective of using high amount of Para-rubber.

5.5 Effect of Cement and Para-rubber Contents on Indirect Tensile Strength

The summary of the performance test results is shown in Table 3, noted that the numbers represent the mean of 3 samples. The result indicated that the mean *IDT* of SC were generally higher than SCP. The samples using the soil from Chonburi had higher *IDT* than the soil from Chainat. Expecting that cement content was an important factor for the increasing of the *IDT* of the samples. In contrast, Para-rubber resulted in a decrease in the *IDT* of the samples.

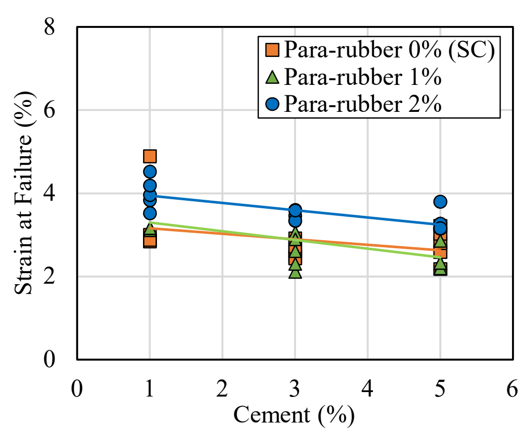

Fig. 8 Strain at failure of treated soils from Chainat

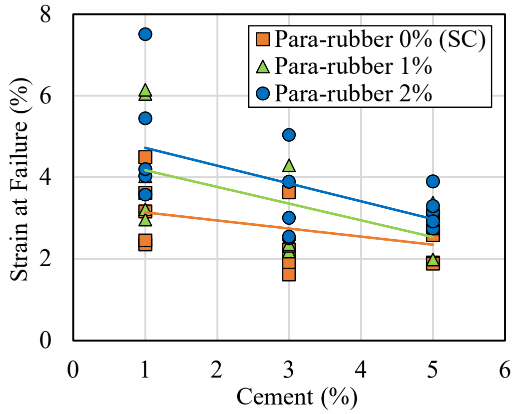

Fig. 9 Strain at failure of treated soils from Chonburi

5.6 Effect of Cement and Para-rubber Contents on Resilient Modulus

The test results of *MR* are also shown in Table 3. An average *MR* of SC was generally higher than SCP. It was also found that *MR* measured from the samples from Chonburi was lower than the samples from Chainat which was in contrast with the results of *IDT*. Expecting that the quality of lateritic soils is an important factor to the increasing of *MR* of compacted samples. Para-rubber, again, resulted in a decrease in *MR* of the samples.

Table 3 Summary of the performance test results

Test	Chainat		Chonburi	
	SC	SCP	SC	SCP
IDT (kPa)	424	234	513	428
MR (MPa)	15,234	10,103	7,435	6,547
FR (No. of cycle to failure)	64	964	28	458
k (cm/sec)	4.3×10^{-7}	3.0×10^{-6}	1.4×10^{-8}	1.3×10^{-8}

5.7 Effect of Cement and Para-rubber Contents on Fatigue Resistance

The results, shown in Table 3, indicated that SC had lower *FR* than SCP when considering at the same amount of applied stress ratio. However, it is noteworthy that the test that uses equivalent applied stress ratio is the test that many researchers have been used to compare the performance of studied materials assuming that those materials have similar response under the same repetitive load. However, the applied stress ratio clearly depends on the *IDT* of each material. In this study, the applied stress ratio was 40% for the soil from both sources, however, the applied loads were different, 170 kPa and 94 kPa for the soil from Chainat and Chonburi, respectively. This study also only limited to the laboratory condition as the samples were cured under controlled conditions, wrapped in room temperature. However, the materials on the construction sites are normally exposed so there might be some deterioration due to the environment, temperature, humidity etc. which could affect the performance of the materials.

5.8 Effect of Cement and Para-rubber Contents on Soil Permeability

The results of *k* test, presented in Table 3, indicated that the *k* of SC prepared from the lateritic soil from Chainat was lower than SCP, suggesting that the SCP had higher void ratio than SC. This could also specify that the Para-rubber affected the quality of compaction or even the generation of hydration reaction. However, when using the lateritic soil from Chonburi, it was found out that the *k* of both SC and SCP were not much different. It is expected that the soil from Chonburi had more fine particles leading to a less effect on *k*. Also, as a result, the samples from Chonburi had lower *k* than the samples from Chainat because it had higher fine content and higher plasticity.

6. CONCLUSIONS AND RECOMMENDATIONS

The study showed the effect of cement (1, 3 and 5% of dry weight) and Para-rubber (60% DRC at 1 and 2% of dry weight) contents on the properties and performances of SC and SCP from 2 lateritic soils that have different basic properties. The results of the study showed that the increase of cement content resulted in higher *UCS* and *Vs*. However, the addition of Para-rubber tended to decrease both properties. On the contrary, the strain at failure increased with the increasing of Para-rubber. This suggested that the Para-rubber might affect the compaction quality due to the partial bonds of Para-rubber and, probably, affected the creation of hydration reaction due to the substitution of water to Para-rubber. Nonetheless, microstructure analysis is recommended for further study.

The performances of the materials were also affected by the addition of Para-rubber. The *IDT* and *MR* tended to decrease, while *FR* and *k* tended to increase after adding 2% of Para-rubber into the mixture. It can be concluded that the use of cement increased the brittleness of the material, resulting in higher strength, while the use of Para-rubber increased the ductility, resulting in lower strength but could be benefited from higher deformation and higher fatigue crack resistance.

However, this study did not cover the durability against wet-dry cycles which is important for the pavement structure design of tropical countries Hence, further study on the test is also recommended.

7. ACKNOWLEDGEMENTS

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