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Research article

Utilisation of Reclaimed Asphalt Pavement for Improving Substandard Subbase

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Abstract: This research attempted to improve substandard subbase by mixing it with reclaimed asphalt pavement. Three substandard soils, namely Soils A, B, C, and RAP, were collected from Phangnga, Southern Thailand. Each soil was mixed with the RAP having the soil to RAP by-weight ratios of 100:0, 90:10, 80:20, 70:30, 60:40, and 50:50. A whole RAP, namely sample D, was also studied, resulting in a total of 19 soil-RAP mixtures. Several testing techniques were carried out to obtain the best mixture for being employed as a subbase. Besides basic properties, the compaction test was conducted to obtain optimum water content. Consequently, such water was employed to prepare samples for the CBR test. Considering overall compaction behaviour, it was found that the maximum dry density gradually increases with the increase of RAP content from 0% up to 30%. After that, it decreased steadily with further increases in RAP from 40% to 50%. Strikingly, all soils had the maximum dry densities when mixed with 30% RAP. As such, the CBR results unsurprisingly showed the same trend, i.e., the maximum values occurred when the mixtures contained 30% RAP. The CBR values for the samples A70R30, B70R30, and C70R30 were 11.0%, 15.9%, and 25.1%, respectively. This indicates that only soil C mixed with 30% RAP qualifies for subbase. These results suggest that 30% of RAP is the most appropriate portion to be mixed with substandard subbase soil to achieve a qualified subbase.

Keywords: Reclaimed asphalt pavement; Substandard subbase; Road construction

1. Introduction

According to the Department of Highways, Thailand, a total of 80,694.355km of roads, including 6,279.653km of concrete pavement, 74,375.009km of asphaltic concrete pavement, and 39.693km of compacted soil pavement, were supervised by the Department of Highways [1]. Additionally, 49,653.785km of minor roads were administered by the Department of Rural Roads, Thailand, the majority of which–46,236.177km–are asphaltic concrete pavement [2]. Considering these numbers, it is evident that most road networks in Thailand are asphaltic concrete pavement. Note that the fact also applies to other countries. Because Thailand is located in a tropical climate, asphaltic pavement is more prone to deterioration than other countries located in mild climate areas. Furthermore, overloaded trucks are normal in the country, exponentially increasing the degree of road damage. As a result, the asphaltic concrete pavement in Thailand requires either repair or even replacement more often than it should be. Consequently, when peeled, an enormous quantity of such deteriorated pavement needs to be managed somewhat. From this information, there is no doubt that the same problem of managing waste worldwide is vital. Nowadays, the term RAP has been used for either reclaimed asphalt pavement or recycled asphalt pavement material. The RAP, as shown in Fig. 1, is asphaltic concrete retrieved from deteriorated pavement utilising ripping, cold milling, or hot milling, depending on the availability of machines. Then, it is crushed to be smaller in order to obtain the required sizes concerning intended usage.

Authorities, organizations, and research institutes have long been inspecting a solution for using RAP; otherwise, a huge area is essential for storing this waste. Considering its composition, recycling it back as asphaltic pavement seems quite sensible. It should be noted that the RAP may be employed in the forms of hot recycled asphalt (HRA) or cold recycled asphalt (CRA). Advantages and disadvantages for both HRA and CRA can be found in Saeed et al. [4]; Wang et al. [5]; Arámbula-Mercado et al. [6]; Mollenhauer et al. [7]; Taherkhani et al. [8]; Chegenizadeh et al. [9]; DOH [10].

Figure 1. Example of reclaimed asphalt pavement [3]

Table 1. Typical properties of RAP [11]

No.	Parameter	Value	Unit
1	Density	1900 - 2250	kg/m^3
2	Moisture content	Max. 3 - 5	%
3	Asphalt content	5-6	%
4	Asphalt penetration at 25 degrees Celsius	10 – 80	Penetration unit
5	Compacted density	1500 - 1980	kg/m^3

Generally, asphaltic concrete is constructed by binding mineral aggregates together using bitumen. Note that the bitumen is interchangeably called asphalt. When the RAP is employed, the compositions include bitumen, coarse aggregate, and RAP. In other words, some aggregate is reduced to some degree by introducing the RAP, resulting in lower construction costs. Bearing in mind that typical properties of RAP slightly vary due to the origin of its compositions. However, one can find the typical properties of RAP reported by Kumar et al. [11], as shown in Table 1.

The HRA has been the most popular for pavement recycling, especially when mixing the RAP with conventional asphalt. For such cases, the RAP acts as a conventional aggregate but has properties quite different from those of common aggregates; the bitumen acts as a binder. It is no surprise if one would think that, in terms of load-bearing capacity, the conventional asphaltic concrete pavement is better than that of pavements built by employing the RAP. However, Mittal et al. [12] showed that adding RAP improves the performance of bituminous mixes. Furthermore, based on laboratory tests by Mittal et al. [12], employing 20% of RAP improved the properties. It should be noted that their findings were based on laboratory work, one must consider actual field conditions as well as machine and construction techniques to be utilised. In addition, Saberi and Mohamed [13] showed that soil mixed with 20% RAP could be employed as road shoulder material. Hasan et al. [14] also found that RAP-soils mixtures have a better resilient modulus of subgrade, thereby increasing the resistance to applied confining pressure. To stabilise a soil that has some plasticity, adding a small amount of cement when mixed with RAP was recommended by Edeh et al. [15]. They showed that adding some cement could also reduce the RAP portion in a mixture to obtain the best results.

Khosla et al. [16], investigated the optimum asphalt binder contents (OAC) to be mixed with RAP. According to their study, the RAP was first blended with virgin aggregates to have desired gradations, and the RAP varied between 8% and 45%. It was found that the optimum asphalt content ranged from 5.4% to 6.0%. These findings suggested that the first step in employing RAP as the asphaltic pavement is to obtain an appropriate mixture between the RAP and virgin aggregate. Then, the OAC is obtained by varying its contents to achieve an optimum mix.

Ariffin [3] stated that roadways' performance when employing RAP degrades with time because the pavement is constructed from recycled, hardened asphalt pavement. Therefore, ongoing research is considering using bio-based rejuvenators because they have tiny molecules that can fill the void. As such, the overall performance is improved somewhat. Ariffin investigated the addition of rubber seed oil (RSO) as a rejuvenator for RAP. The RAP had an asphalt content of 4.04%. The sample was prepared in the Marshall compactor mould of 100mm diameter. It had an RAP of 1000g, and the RSO and water content were 3.25% and 3-5%, respectively. The bitumen required for laboratory tests, including bulk unit weight, air voids, Marshall stability, and Marshall flow, was 40.4g, corresponding to 4.04%. The mix design employed the two temperature levels of 0°C and 45°C; the results are shown in Table 2.

Table 2. Result for Mashall mix design for 0°C and 45°C [3]

Water content (%)	Avg. SG bulk		Avg. air voids (%)		Avg. stability (kN)		Avg. flow (mm)	
	0°C	45°C	0°C	45°C	0°C	45°C	0°C	45°C
3	2.12	2.09	16.92	18.00	12.80	12.67	3.05	3.01
4	2.14	2.14	16.01	15.89	13.02	12.93	2.91	2.97
5	2.13	2.14	16.24	16.05	12.71	12.58	3.52	4.05

Plati et al. [17] studied the possibility of employing RAP as unbound pavement layers. Please note that most RAP research has emphasised on recycling as asphaltic concrete pavement; thus, information concerning the unbound pavement is scarce. By making use of the RAP, it would benefit the environment in terms of waste management. The RAP used in their study was from a milling process of rehabilitating a pavement section. Then, the RAP was mixed with virgin aggregate (VA), which had varied proportions. Five blends were studied: A, B, C, D, and E. The percentage ratios between RAP and VA for the respective five blends were 0:100, 10:90, 20:80, 30:70, and 40:60. Next, several laboratory tests, both basic and engineering properties, were carried out to obtain suitable results. For the modified Proctor test, Plati et al. reported that the optimum moisture contents for the blends narrowly vary from 5.9% to 6.9%. As the proportion of RAP gradually increased, it was found that the maximum dry density was progressively decreased; the maximum density of 2,196 kg/m^3 was found for blend A, and the minimum density of 2041 kg/m^3 was found for blend D, showing only slight difference. For the CBR test, the results revealed that the higher the RAP portions, the lower the CBR values. Nonetheless, the minimum CBR obtained from blend E (40% RAP and 60% VA) was still just over 50%, but indicating enough strength. Plati et al. also conducted the triaxial test to obtain other strength parameters for more complex problems.

It has been shown that most studies concerning RAP emphasise on mixing it with bitumen to recycle it back as asphaltic pavement. However, considering its shape, size, and properties, the RAP has a high potential to be employed as a subbase. In addition, if properly mixed with other granular materials, the mixture may also be directly employed to construct a Macadam Road. Nonetheless, for both cases, several tests must first be carried out in order to obtain appropriate proportions.

This research attempted to improve substandard subbase soil by mixing it with RAP. Three substandard subbase soils obtained from Phangnga, located in Southern Thailand, were mixed with the RAP obtained from the same region to achieve the objectives. Each soil-RAP mixture had varied mixing ratios. Then, basic and engineering properties were determined using the testing standards provided by the Department of Rural Roads, Thailand.

2. Materials and Methods

According to the standards provided by DRR [18], subbase materials must have a CBR of 25% or higher. When tested using the modified Proctor method at 95% of maximum dry density, the CBR value is one of the most important parameters. Other properties of a suitable soil include less than or equal to 35% of the liquid limit and a plasticity index of not more than 11%. Table 3 displays the gradations of materials suitable for being employed as a subbase for road construction. It should be noted herein that having natural soil with such required properties is almost impossible. Therefore, mixing two or more soils in order to obtain a targeted property is not unusual.

Table 3. Gradation of material suitable for subbase [18]

Sieve size	Percentage passing of material				
	Type A	Type B	Type C	Type D	Type E
2′′	100	100	-	-	-
1′′	-	-	100	100	100
3/8′′	30 – 65	40 – 75	50 – 85	60 – 100	-
# 10	15 – 40	20 – 45	25 – 50	40 – 70	40 – 100
# 40	8 – 20	15 – 30	15 – 30	25 – 45	20 – 50
# 200	2 – 8	5 – 20	5 – 15	5 – 20	6 - 20

Table 4. Soil to RAP ratios by weight

Sample number				Soil to RAP ratio (by weight)	Note
Soil A	Soil B	Soil C	D (Milling)		
A100R0	B100R0	C100R0	-	100:0	
A90R10	B90R10	C90R10	-	90:10	
A80R20	B80R20	C80R20	-	80:20	
A70R30	B70R30	C70R30	-	70:30	
A60R40	B60R40	C60R40	-	60:40	
A50R50	B50R50	C50R50	-	50:50	
-	-	-	R100	0:100	100% of RAP

In this study, a total of three soils from Phangnga Province were chosen, but from different areas, as a base material to be mixed with RAP, namely Soil A, Soil B, and Soil C, as shown in Fig. 2. In addition, the RAP was also collected from the same province. Fig. 3 illustrates the equipment and processes for milling the RAP. Previous studies [19-23] show that even though RAPs were collected from different places, their properties are quite similar. This may be because the constituents of asphaltic concrete, no matter where it is constructed, are very much the same. Nonetheless, for the consistency of test results, only one source of RAP was chosen; it was also from the same province of Phangnga. To obtain the optimum proportion in terms of the highest CBR, each soil was mixed with the RAP having the soil to RAP by-weight ratios of 100:0, 90:10, 80:20, 70:30, 60:40, and 50:50. In addition, 100% of RAP, namely sample D, was also included for the laboratory work so that they could be compared for further analysis. This resulted in 19 samples for laboratory tests, as shown in Table 4.

Besides basic properties such as soil classification and Atterberg limits, the following tests were carried out to achieve this study's objectives: modified compaction test and California Bearing Ratio test. The compaction test during operation is shown in Fig. 4, while Fig. 5 displays the procedures for the CBR test. Although all laboratory tests were conducted according to the standards set by the Bureau of Testing Research and Development, the Department of Rural Roads, Thailand, the methods are indeed based on the international standard, namely ASTM.

Figure 2. Soil sampling (a) soil A (b) soil B (c) soil C

Figure 3. Collecting the RAP (a) milling machine (b) milling machine in operation (c) pavement after RAP peeled (d) depth of peeled surface (e) pile of milled RAP (f) collecting RAP

Figure 4. Compaction test (a) preparation of soil and RAP (b) soil compaction test in operation (c) taking measurements for density calculation

Figure 5. California Bearing Ratio test (a) sample preparation (b) sample being compressed (c) soaked samples for swelling determination

3. Results and Discussion

The main objective of this study was to improve a soil that is not good enough as a subbase by mixing it with RAP. Commonly, a soil that could be employed as a subbase should have a CBR of 25% or higher. Several factors affect the compaction and CBR behaviours, but one of the most important factors is size distribution characteristics. Fig.6 displays the size distribution curves for Soils A, B, and C as well as the RAP employed in this study. Soil A was classified as clay with low plasticity according to the Unified Soil Classification System, CL. In contrast, soils B and C were classified as SM, mostly sand-sized material with some silt and clay. It can be seen that only Soil C has a size distribution similar to that of the RAP. In addition, soil A has the smallest range of soil particles. These characteristics would provide insight into what will happen when conducting the compaction and CBR tests.

Table 5 summarises the laboratory work carried out by this study, including sample number, maximum dry density, 95% of maximum dry density, optimum water content, soaked CBR, and swelling of soaked samples. For all soils A, B, and C, when considering overall compaction behaviour, it was found that the maximum dry density gradually increases with increasing RAP from 0% to 30%. Subsequently, when the RAP was increased to 40% and then 50%, the maximum dry density decreased with the increase of RAP. Strikingly, the maximum densities for all soils were met at the same mixture with the RAP of 30%. Hence, it was interesting to look at this result by plotting their corresponding compaction curves obtained from the compaction test, as shown in Fig. 7 (a), (b), and (c) concerning the sample numbers A70R30, B70R30, and C70R30. From the figure, the maximum dry densities for the sample numbers A70R30, B70R30, and C70R30 are 1.521, 1.616, and 1.719 g/cm^3. When considering their size distribution characteristics, as shown in Fig. 6, it suggests that the greater the range of soil particles–soil mass has a wide range of particle sizes–the higher the maximum dry density. This is because soil with a broader particle size range would be highly compactable, resulting in higher density. Results similar to these findings are also found from Alhaji and Alhassan [24]; they concluded that the maximum dry density of black cotton soil mixed with RAP was achieved when the RAP content was about 30%. Nonetheless, Suebsuk et al. [25] reported that the maximum dry density of lateritic soil mixed with RAP was obtained when the RAP content was 50%. It should be noted that, however, their soil contained a higher amount of fine.

Fig. 8 (a) shows the relationship between maximum dry density versus the increase of percentage RAP, while Fig.8 (b) displays the corresponding optimum water content versus the percentage RAP. It revealed that the maximum density occurs at the same amount of RAP of 30%, as already discussed. Nonetheless, when considering the optimum water content, it showed that the higher the percentage of RAP, the greater the OWC. This may be because as the RAP portion is gradually higher, more water is required for the compaction test.

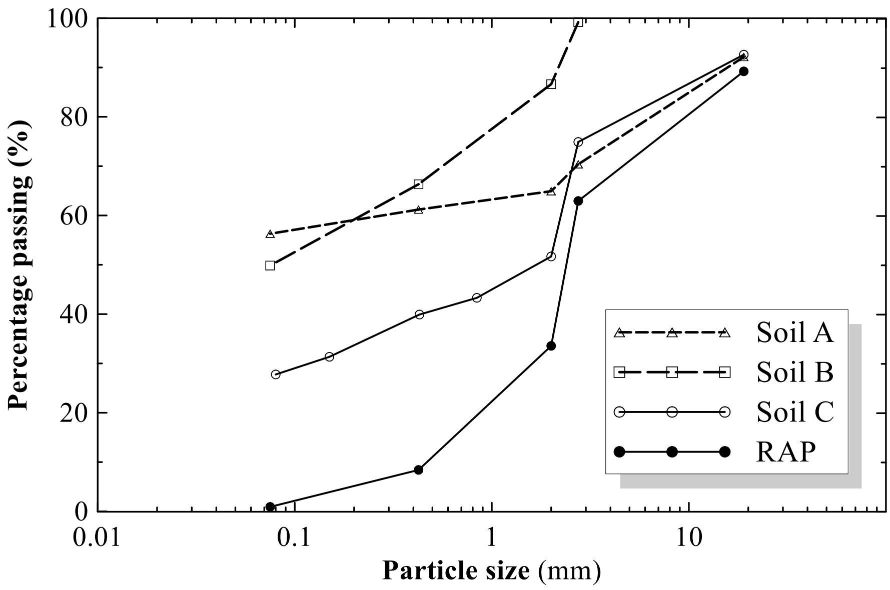

Figure 6. Size distribution curves for all three soils and the RAP

Table 5. Summary of laboratory work results

Soil	Sample no.	Max. dry density (g/cm³)	95% of Max. dry density (g/cm³)	Optimum moisture content (%)	Soaked CBR (%)	Swelling (%)
A	A100R0	1.455	1.382	14.7	7.9	8.4
	A90R10	1.487	1.412	15.0	8.8	6.8
	A80R20	1.510	1.435	15.7	9.6	5.8
	A70R30	1.521	1.445	16.1	11.0	3.5
	A60R40	1.505	1.429	17.0	9.1	2.9
	A50R50	1.485	1.411	17.6	8.3	2.8
B	B100R0	1.567	1.429	10.9	13.2	4.4
	B90R10	1.585	1.506	11.5	13.4	3.9
	B80R20	1.595	1.516	12.8	14.6	3.5
	B70R30	1.616	1.535	13.2	15.9	3.0
	B60R40	1.588	1.508	14.0	14.2	2.8
	B50R50	1.577	1.429	14.2	13.8	2.2
C	C100R0	1.601	1.521	12.8	16.5	4.9
	C90R10	1.665	1.582	13.5	17.3	4.3
	C80R20	1.698	1.631	15.0	21.5	3.4
	C70R30	1.719	1.633	16.1	25.1	2.9
	C60R40	1.657	1.574	17.6	22.3	2.3
	C50R50	1.641	1.559	19.7	17.6	1.8
D	R100	1.921	1.825	10.9	20.9	0.3

The CBR values for all soils A, B, and C having zero RAP were 7.9, 13.2, and 16.5%, respectively, corresponding to the sample numbers A100R0, B100R0, and C100R0, of which are lower than the standard CBR value of 25% for being employed as subbase. In addition, for the whole milled RAP sample (sample number R100), the CBR was just 20.9%; it is quite high compared to all soils, but it is still not good enough.

The changes in CBR values versus the increase in percentage RAP are shown in Fig. 9 (a), while Fig. 9 (b) displays their corresponding swelling values versus the percentage RAP. The CBR behaviour showed the same trend as found in the compaction test: the CBR gradually increased with the increase of the RAP portion from 0% up to 30%, then gradually decreased till the maximum RAP portion of 50%. The most interesting point, however, is the swelling results. It was found that they steadily and gradually decreased with the increase in the percentage of RAP. As mentioned before, the maximum dry density and CBR for all soils A, B, and C were maximum when the percentage of RAPs was 30%. Consequently, the percentage swelling values for soils A, B, and C are the lowest when the mixtures contain 30% RAP. This means that when 30% RAP was added, even when fully soaked, the void ratios were also the lowest. Hence, the finding strongly confirms that the 30% RAP is the optimum value for mixing with the tested soils to obtain the best parameters for being subgrade material. Nonetheless, for all of the samples studied, only the sample number C70R30 is qualified as a subbase material. As such, the findings imply that even though to be mixed with RAP, soil must be carefully chosen to obtain the required results: soil should have a wide range of particle sizes with a small amount of clay. This is because higher clay content in soil may cause a swelling value to increase substantially, thereby posing the instability of a road. It should be noted herein that these results, particularly of the sample C70R30, show a promising sign because other studies tend to add some substance, such as cement, to achieve a similar CBR. Still, no other materials are required for this study. Thus, it helps in terms of both cost and environment. This is because employing cement, for example, could generate a more significant carbon footprint, thereby worsening pollution.

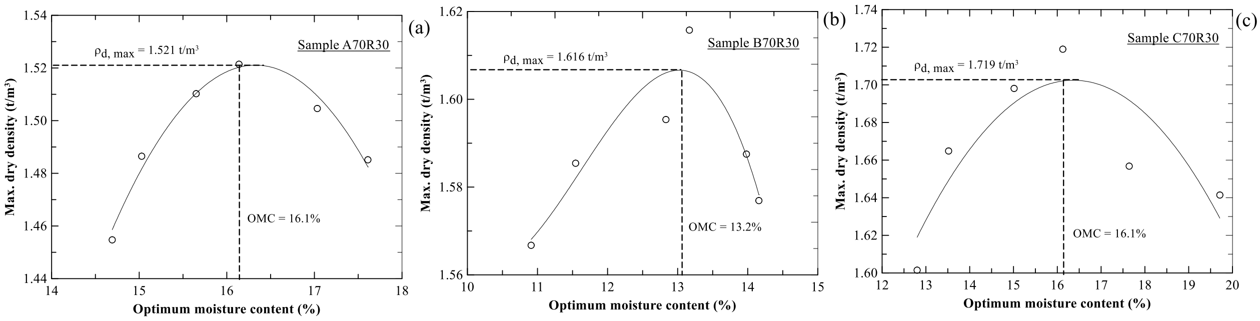

Figure 7. Maximum dry densities for (a) sample A70R30 (b) sample B70R30 (c) sample C70R30

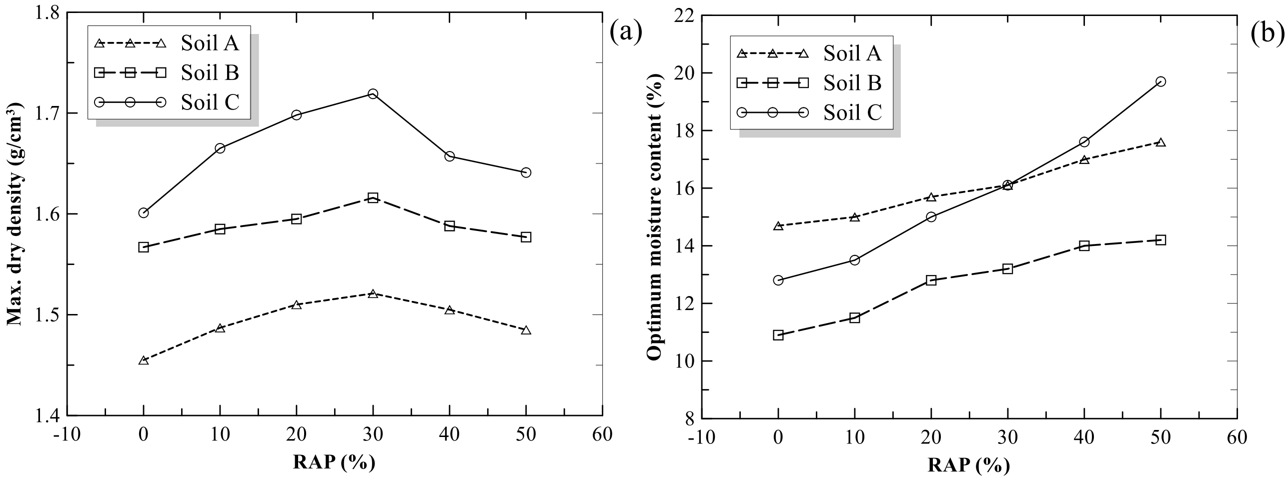

Figure 8. (a) Maximum dry density versus percentage RAP (b) Optimum water content versus percentage RAP

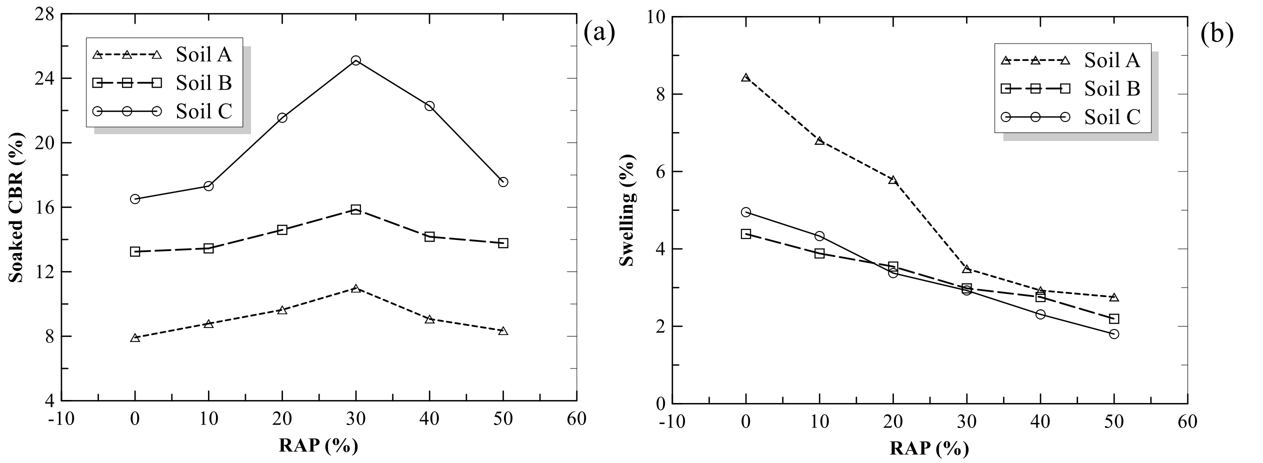

Figure 9. (a) Soaked CBR versus percentage RAP (b) Swelling versus percentage RAP

4. Conclusions

Road networks are vital for economic growth. The construction, however, requires a great deal of natural material, especially soil and rock. Even though both materials are abundant, not all encountered soil and rock are appropriate for road construction: they must possess specific characteristics that can keep up with traffic loads and ambient weather. When a road project has been committed, one of the most priority tasks is to source materials as close to the site as possible. This is because if the main materials are quite far from the project, transportation costs would be so high that it is not viable. As such, soil close to the project but with substandard quality could be employed with some modifications.

This research attempted to improve soil that is unsuitable for being employed as a subbase by mixing it with RAP. Three substandard subbase soils, namely Soils A, B, and C, were collected from different areas in Phangnga province, Southern Thailand. In addition, the RAP was also milled in the same province. Both basic properties and engineering properties for the soil-RAP mixtures were determined in laboratory using the standards set by the Department of Rural Roads, Thailand. Note that even though the testing standards were domestic, they are equivalent to the international standards set by, for example, ASTM. The soil-to-RAP ratios by weight of each soil type for the laboratory work were 100:0, 90:10, 80:20, 70:30, 60:40, and 50:50. In addition, testing a whole RAP was also carried out so that all results would be compared and contrasted. This resulted in a total of 19 mixtures that were tested and examined. From the laboratory tests and analyzed data, the following points have been drawn:

(1) The classification results show that soil A is classified as CL, while soils B and C are classified as SM.

(2) The CBRs for the sample numbers A100R0, B100R0, and C100R0 were 7.9%, 13.2%, and 16.5%, respectively. They were lower than the standard value of 25% for being employed as a subbase. Even though the whole RAP (sample number R100) had a CBR of 20.9%, which is quite greater than that of all soils, it was still not good enough. Hence, all sampled soils met the requirement for this study: they must have a CBR lower than 25%.

(3) For all soils, the maximum dry density gradually increases with the increase of the RAP portion from 0% to 30%. Then, they steadily decrease with the further increase of the RAP portion from 40% to 50%. The maximum values for soils A, B, and C are 1.521, 1.616, and 1.719 g/cm^3, respectively; they occur when the samples contain an RAP of 30%. This means soil C has the highest capability for being compacted.

(4) The CBR behaviors were similar to those of the compaction test results. The maximum CBR values for all soil occur when the samples also contain an RAP of 30%. The maximum CBR for soils A, B, and C are 11.0, 15.9, and 25.1%, respectively. These results indicate that only soil C mixed with 30% of RAP could be used as a road construction subbase material.

(5) When considering the CBR results, one should also examine their corresponding swelling potential. In this study, it is striking that all samples with 30% RAP also have the lowest swelling. This means that the results obtained from this study firmly validate that when the soils were mixed with 30% of RAP, they were most effective regarding compaction ability and puncture resistance.

Even though the results from this study confirm the possibility of mixing substandard subbase soil with RAP to be employed as a subbase in road construction, we should carry out more studies. This is because only three soil types were tested; if more soil types are to be studied, their results would be beneficial for further comparison to confirm the feasibility of this kind of modification. Furthermore, other substances, such as cement and lime, may be included in mixtures to assess their effects. If only a small percentage of cement and lime are required for a soil-RAP mixture to have enough CBR, a wider range of soil types may then be applied by this modification technique. Therefore, one would not worry when a road construction project is close to substandard soil. Please note that this study did not concern the permeability behaviour; if interested, however, one can find the behaviour from Akinwumi [26], Gowda et al. [27], and Russo et al. [21]. Additionally, if the unconfined compression is concerned, one should investigate the study conducted by Lima et al. [28]. They mixed RAP with pure soil using a percentage of RAP ranging from 0% to 80%, with and without the addition of cement. Other similar studies can also be found in [29-31].

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Conflicts of Interest: The authors declare that there is no conflict of interest involving this research.

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