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Article

Use of Natural Rubber Latex (NRL) in Improving Properties of Reclaimed Asphalt Pavement (RAP)

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Abstract. Many issues, especially cost, need to be looked at when a new asphalt materials are considered for road construction. One major factor that impacts the cost is the volatility in oil price and stock availability. Consequently, this factor affects both road construction and maintenance by creating uncertainty and financial challenge for Thai manufacturers. Furthermore, all economies, either national or local, depend on adequate road infrastructure and their sound maintenance for growth and development. One strategy for reducing the overall cost of road construction is through reclamation of existing pavement surfaces that are being repaired or replaced. A process of recycling asphaltic concrete pavement known as Reclaimed Asphalt Pavement (RAP) has been employed in many countries. However, one drawback associated with this practice is the costly investment in the mixing equipment which mechanically rejuvenates the old asphalt pavement by blending it with new asphalt binder. In addition to the high cost of investment, the required quality of the RAP has not been assured due to the lack of enough evidence. The addition of Natural Rubber Latex (NRL) to the process of the recycling asphalt pavement with the aim of reducing production costs and improving the quality of the RAP, offers a promising solution. This paper describes the results of an investigation into the properties of reclaimed asphaltic concrete mix with added NRL. The properties investigated include the Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR). The results show that properties of the NRL modified RAP mix meet the required engineering specifications. The results show that mixing NRL content of 5-15% by weight with RAP and cement content of 3-7% produced a mixture that meet the specification of Thailand Department of Highways in terms of UCS and CBR value for use in layers of pavement. Apart from the positive environmental impact of using recycle material of RAP, the economic and financial benefits to Thailand and rubber farmers make it worthwhile to use this NRL modified RAP for road construction and maintenance.

Keywords: Reclaimed asphalt pavement, natural rubber latex, road construction.

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1. Introduction

Thailand is the largest rubber producer in the world. According to the figures from 2015 of the total global production, Thailand produced 35.7% followed by Indonesia (26%), China (7%), India (6%), and Malaysia (5.5%) [1]. Currently the market is experiencing low pricing because global demand is decreasing while inventory is increasing. New avenues for utilization of rubber are required to sustain the market and the rubber farmers. The previously expressed proportion of composition with regards to NRL and RAP needs to be analyzed and field tested in Thailand for proof that the process would be both effective and economically sound.

At present, the major usage of rubber domestically is in commercial products such as rubber gloves, condoms, and cars. This demand does not use up the stock sufficiently enough to maintain a viable market. Farmers are being forced to sell at prices below production cost due to a reduced demand and glut of inventory collectively.

The production and usage of rubber with regards to road construction is divided into two main categories:

1) Para Cape Seal Type which uses 5 percent of rubber in asphalt emulsion. From the proportion of current paved road surface which is 6 meters wide, it requires about 300 kilograms of rubber per 1 kilometer of pavement. Thus, 1 kilometer of road length requires 1,000 kilograms of rubber latex.
2) Para-Asphaltic Concrete which uses about 5% of rubber as a component of asphalt binder. From the proportion of paved road surface which is 0.04 meter thick, 6 meters wide, and 1 kilometer long, it requires 1,440 kilograms of rubber [2].

2. Literature Review

2.1. Pavement Materials

Hongentogler (1938), explained that the improvement of soil properties is to make the natural soil have the ability to better bear weight and withstand erosion. The improvement method may be from either compaction or use of admixtures.

Winerkorn (1955), explained the improvement of soil properties by bringing physical and chemical methods to mix with the soil to improve engineering properties.

Kennedy and Oleson (1987), have made Mixed In-Place Recycling by using cement and other materials as admixtures since 1984 in England.

Vichit cholchai et al., (2012), studied the improved longevity of asphalt quality for road construction throughout the lifespan of the road. They used Polymer Modified Asphalt (PMA) mixing of additive polymers to improve its quality. Natural rubber has the propensity as an additive polymer to improve stability, elasticity, and fatigue resistance. The research studied the proper ratio of asphalt cement and rubber required to obtain the desired properties. Their analysis of asphalt cement quality included softening point, penetration index, ductility, torsional recovery, toughness-tenacity, and viscosity. In the research, the appropriate proportion of asphalt and rubber were determined to produce components according to the specified properties and viscosity. It was found that the mixture of rubber at 6% gave the best quality of asphalt binder. Pavement that used this mixture demonstrated high tensile strength. Additionally, the higher viscosity of asphalt did not cause problems in mixing with aggregate components in the asphaltic concrete production.

Tuntiworawit et al., (2005), studied and tested the engineering properties of asphalt cement and asphalt concrete mixed with natural rubber in the form of rubber latex by focusing on finding out the appropriate proportion of rubber latex required in the mixing process. To achieve Natural Rubber Asphalt (NRA) from mixing it requires AC 60/70 with high concentrations of ammonia (HA) rubber latex at a content of 1-13% by total weight while being mixed with limestone to produce asphaltic concrete samples. The experiment results showed that the NRA had sound engineering properties. This is a good choice to produce asphalt cement because the natural rubber is abundantly available in the country and suitable for use as admixtures which increase the flexibility, stability and lifetime of the road. This research found that a mixture of 9% latex concentrate provided the best results.

Xiao et al., (2007), studied the improvement of the Rutting resistance properties of asphaltic concrete mixed with rubber for use as road building materials for RAP which was important in stimulating the use of asphalt concrete. In the past, the use of RAP was proven to help save money and reduce environmental problems while increasing the mechanical properties of rutting resistance of asphalt-rubber mixtures. The experiment was designed to use two rubber types including the rubber produced in ambient and cryogenically conditions while having four distinct values and three kinds of sub-rubbers. The experimental results demonstrated that RAP and sub-rubbers in the HMA can improve Rutting resistance properties.

Thongchai Rungrueng (2013), studied the improvement of the asphaltic surface dismantled from the original layer for reuse by studying the improvement of the quality of the cement modified crushed rock material of the original base mixed with the asphalt concrete surface added with cement to gain unconfined compression as required. The cement modified crushed rock base of the recycling base mixed with the reclaimed asphalt concrete with cement consisted of three mixture proportions; 3:1, 1:1, and 1:3 by changing cement quantity within the range of 2 -6 %. The study results indicated that the use of cement and the ratio between weight and cement provided the cement volume at equal unconfined compression in all respects. However, it was found that the ratio use between water weight and cement was more appropriate in terms of the number of samples to be tested. Additionally, when considering the development of unconfined compressive strength of the original stone mixed with cement and the original modified asphalt concrete, the mixture at the ratio of 1 to 3, was not suitable to be used as aggregate material, since the development of strength under the curing phases produced reduced values.

From the literature review, it was found that the cement percentage in bonding was 3%, 5% and 7% and the latex was 5%, 10% and 15%. The overall optimal considerations for road work layers were determined to support a ratio of 3-5% of cement in combination with 5% latex [2, 3, 4, 5, 6].

2.2. Pavement Test Methods

2.2.1. Pavement Structure

Pavement structure (Fig. 1) consists of layers of materials that support traffic loads. The top layer serves to carry the load and distributes the impact down to the lower layers, spreading out into the subbase layer, and to existing soil. Pavement strength depends on the properties of the weight- bearing of materials of each layer in conjunction with a high-quality surface covering on the topmost layer. This top layer must be classified as strong and resistant to the abrasion of vehicle wheel friction while dispersing energy through the lower adjacent material layers and finally into the embankment layer.

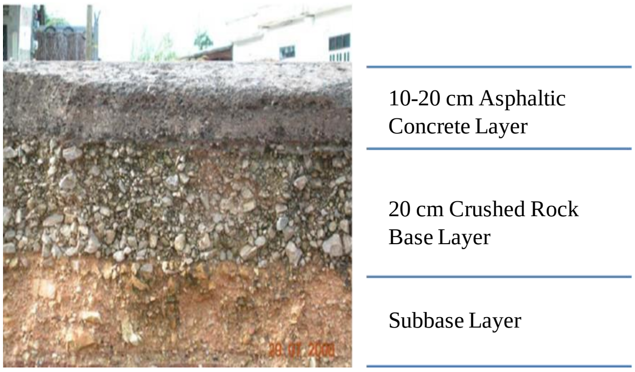

Fig. 1. Material Layers of Pavement Structure.

The material layers of pavement structure as shown in Fig. 1 possess distinct defined functions:

1. The Surface or Wearing Course must be strong and able to directly with stand abrasion and the wheels of the vehicles. It must possess stability when under a traffic load while being non-porous enough to prevent water from disrupting the properties of lower layers. Some commonly used surfaces are as follows:
   1.1. Treated Surface refers to the "wearing course" or the "shoulder surface" paved with asphalt that is sporadically covered with the sub-gravel or gravel sub-materials in a single layer or multiple layers. This also includes the base course or other areas which have already been layered with Prime Coat to prevent flaking and water seeping into the embankment layer. It does not increase the capacity for weight bearing.
   1.2. Asphalt Concrete Surface is a composite material derived by mixing the aggregate mass and the asphalt cement through a mixing process in conjunction with additive heat. The specific temperatures from the heating process accompanied by mixture ratios control the properties of the final product. The mixture is then applied at specified temperature ranges to ensure quality. The mixtures are then paved on the base course that have already been layered with Prime Coat or Tack Coat. Immediately after the paving equipment extrudes the layer it is compacted while it is still hot so as to achieve the required density. For asphalt concrete pavements, the strength quality correlates directly with the weight-bearing properties. Asphalt concrete is a flexible pavement of which the basic concept of its design is the combined thickness of the surface, the base course, and the subbase course (if any) which must be sufficient to reduce the force units occurring from the vehicle wheels. This dispersal of force should be uniform and not result in transferring excessive force to the embankment layer or trigger deformation in the existing soil. In other words, it can not transfer force from one layer that exceeds the capacity of proceeding layers [8, 9].
   1.3. Portland Cement Concrete Surface is the Rigid Pavement which possesses a combination of qualities that includes; strength, copious load-bearing capacity, and long service life. Portland Cement Concrete Surface functions primarily to distribute the load weight from the vehicle wheels and transfer it through to the base course, and then the subbase course. Nevertheless, since the concrete is considered strong with a very high flexibility rating, it disperses the wheel loads onto the pavement in a wide area. Therefore, the ability to bear weight is originated by the concrete itself [12].

2. Base Course is characterized as a stable and very robust layer. Its function is in distributing the force units caused by the wheel loads acting on the surface. It passes these force units into the subbase in a manner so as not to exceed the weight-bearing capacities of subsequent layers. The Base Course is comprised of materials such as crushed rocks, sub-gravels or quality improvement materials. They are described as follows:
   2.1. Crushed Rock Base-This is crushed rock material generated by specified millstone grades that are durable, clean, and contaminate free.
   2.2. Cement Modified Crushed Rock Base-This refers to crushed rock that has been modified through a process of homogeneously mixing cement and water and then subsequently crushing it thoroughly to ensure maximum firmness for the base course.

2.3. Soil Cement Base-This is the material obtained through material quality improvement which is done by directly mixing cement into the soil aggregate in order to create better engineering properties. This method is used for the road construction when the site is located far from available rock resources or in locations where there is a shortage of crushed rocks. Therefore, the base course with cement soil is employed to overcome such a situation. It possesses a high compressive strength and is considered a good material for base course layers. The material used for soil cement is usually low-quality laterite with a CBR value not in accordance with the subbase course standard.

2.4. Recycling Base-This is created by the introduction of the reclaimed materials and/or layers to be stabilized by mixing cement lime or asphalt according to the specification of the designing engineer then simultaneously paving it back and tightly compressing it to use as a Recycling Base before paving the new surface layer on it. This method is sometimes referred to as Deep Recycling which the Department of Highways utilizes for restoring asphalt surfaces in situations where the highways are seriously damaged from the surface layer through the base course requiring increased strength throughout the pavement structure.

3. Subbase Course is underneath the base course, functioning so as to distribute the force out of the base course and into the lower layers while reducing stress in the subsequent layers. Soil Aggregate is the preferred material for this. Though it is of lower quality, it is cheaper and more cost effective. The aggregate materials that are most commonly used are hard and durable with a mixture of good binding materials. They must be well graded while free from clay and weeds and limited to lumps no larger than 50 mm.

4. Selected Material-This is the material that can be found within the immediate construction area. It is of inferior quality in comparison to the Subbase Course material but possesses better quality than what can be found in the embankment layer. It can be used to separate between the subbase courses and Embankment Layer. It can be employed to help reduce the density of the subbase course while reducing construction costs.

5. Rubber-This is an important national economic crop and it is a kind of polymer that can be used to improve the properties of asphalt when used for road construction. According to a study [7] about techniques and the ratio of rubber mixture with suitable asphalt concrete, it was found that the use of Smoked Rubber sheets mixed with asphalt improved the properties of asphalt cement. It was determined that the ratio of 6% latex in regards to total weight is the most suitable proportion due to higher; softening point values, return values, toughness values, tenacity values, viscosity and Penetration Index values. These increased engineering properties demonstrated that the addition of Rubber Latex increased the strength and durability of the road. In addition, it was found that it can be homogenously mixed with asphalt better than that of Smoked Rubber sheets. The suitable mixture ratio of latex for mixing with asphalt cement for road construction in a mixing plant is 5% dried rubber in regards to total asphalt weight.

Fig. 2. Latex at the Rubber Research Center, Hat Yai District, Songkhla Province.

Latex from the rubber tree (Fig. 2) is a white or creamy liquid with rubber particles suspended in a water medium [11]. Rubber particles in round or pear shape are 0.05-5 microns in size, with a density of 0.975-0.980 grams per milliliter and a pH range of about 6.5-7.0. Generally, the amount of rubber found in natural rubber latex is approximately 25-45% and it has the following components:

Table 1. The amount of rubber within latex and the various additional components [4].

Components	Average % (by weight)
All solid substances	36
Protein group substances	1-1.5
Resin substances	1-2.5
Ash	1
Sugar	1
Water	The total amount including other substances is 100

The current production value of latex when rubber is processed is about 33 percent of volume. This percentage is not adequate for adding to the asphalt cement production process. Asphalt cement requires the latex to be at a level of at least 60 percent with relation to rubber volume while maintaining consistent quality throughout the material volume. In order to achieve this desired percentage, the rubber must undergo a reducing type process. There are four methods of concentration that can be employed to generate this; water evaporation, creaming, electrical separation, and spinning. Most manufacturers in Thailand rely on a high-speed spinning method to separate out water and other undesired substances.

2.2.2. Test methods

Compaction Test

Soil compaction refers to the compression of a through process of directly applying mechanical energy. This process improves the physical soil properties and affects the moisture capacity. The tighter or more compact the soil is the more suitable it is for road construction. Loose soil is unstable and the porousness allows for greater water transference or moisture content. Soil can be tightened or compacted by means of applied mechanical vibration and weight. The compaction can be evaluated and tested using the industry standard of Proctor's method. The density of compacted soil depends on not only the amount of water used for compaction, but the compaction method and energy utilized when compacting. For compaction of the same kind of soil using the same quantity of water but different energy in compaction, the density obtained will be different. For the relationship between dry density- water quantity- energy, when the compaction energy is increased, dry density will be higher. When the unsuitable moisture is reduced, dry density will increase on both the dry side and wet side.

Unconfined Compression Test

The evaluation of the strength or power of soil is generally determined through two methods; (1) The soil without induction force which is caused by the electrical-chemical attraction between the soil grains and (2) The friction caused by the abrasion between the soil granules and the stiffness between the surface of the soil grains. Testing is accomplished by utilizing a special ground rod that is forced into the soil and it cores a sample while encapsulating it when retracted. This coring is then placed in a machine that is designed and calibrated for specific tests. A commonly accepted methodology for determining the shear strength of soil centers on using Mohr's formula which is based on tested math. The shear strength refers to the bond between soil grains in induced soil. The symbol representing this is (c). The induced soil may include clay. When the soil is compressed, it will cause stresses at the contact surfaces. If the soil is in a loose condition, it will cause the soil grains to hold together tightly and reduce the gaps between the soil grains. But if there is an accumulation of forces such that there are no gaps left in the soil, or the force of action increases so quickly that the contact surfaces between the grains cannot increase, it will result in a potential force within the soil mass. The soil is then considered to be in an unbalanced condition causing the soil mass to be potentially catastrophic in relation to failure. The plane of the catastrophe is called the plane of soil shear strength. This represents the maximum shear strength unit that the soil can stand. It consists of the cohesion force naturally occurring between the soil grains based on both electrical charges and chemical reactions. This soil property is called cohesion. The friction to resist the movement between the soil grains is called internal friction. This will depend on the compressive force the soil mass is exposed to. It can be measured by the ϕ angle of Internal Friction.

Unconfined Compression Test is a non-consolidation test which is commonly used with shear strength testing of saturated clay in the surrounding pressure being zero, with the vertical force acting on the sample soils quickly. This experiment is an easy way to determine the non-dehydrated shear forces without having to consider the change in water quantity in the soil mass during the experiment. In this kind of experiment, the angle of internal Friction (ϕ) can not be figured out because this experiment will be quickly conducted before the water has the opportunity to drain out. The shear strength is equal to half of the ultimate compaction unit which is 2SU when SU is UCS compression strength and sometimes use the symbol (c) as $c = qu/2$ when qu is the ultimate compressive strength of the unlimited soil [10].

California Bearing Ratio Test

In 1992, the California Division of Highway determined a method for classifying soil properties for use in the selection of suitable materials for road construction. During World War II, it needed to develop an airport that could bear the weapon load of the Air Force. The United States Army Corps of Engineers Unit then successfully adopted the CBR qualification testing method to design the airport runways. The purpose of soil compaction is to increase the capacity of the soil strength. This also affects the seepage of water through the soil mass and corresponding collapsing and swelling due to water retention. This method eventually became an accepted evaluation tool with respect for the embankment layer, subbase course, and base course. In a general construction plan, the density of a soil layer will be determined so that each layer for compaction is as a % of CBR. The % of CBR is scaled so that the higher the number directly corresponds to higher compaction. CBR is then employed to find the shear strength of soils or crushed rocks which have already been compacted. The values obtained from the test are in the form of resistance units of the tested soil compacted per standard weight unit of crushed rocks compacted respectively in the depth or the penetration piston, which is equal in a comparison percentage. CBR testing can be done immediately after soil compaction. If the soil mass has a water quantity lower than that found in the soil causing the optimum moisture content (OMC), the result CBR value will be higher than the compacted soil mass with water content in the soil higher than the OMC value. If the compacted soil is taken after saturation in water for 4 days, the CBR value close to OMC will result in an ultimate CBR value, swelling the soil when immersed in water before the CBR experiment.

Standard or modified soil compaction experiments will obtain the highest dry density and water content reflecting the soil being the most cohesive. Each soil sample has unequal highest cohesion values. The experiment to find CBR values is to find the load capacity of each soil with the highest dry density. If the density is high, the CBR will be accordingly high as well. The soil properties suitable for transportation engineering work are determined by cumulative soil CBR values. The CBR test is a method of finding the weight bearing of the compacted soil by using a piston with 3 square inches of cross-sectional area to press on the soil sample. If the greater % of CBR is determined, that layer must be accordingly more compacted and subsequent CBR testing which is calculated to figure out soil shear strength values and compare them in percentage.

Table 2. CBR relationship standard and suitability for use [13].

%CBR	Rating	Uses
0-3	very poor	subgrade
3-7	poor to fair	subgrade
7-20	fair	subbase
20-50	good	subbase, base
>50	excellent	base

CBR Test is a method for comparing the shear strength of compacted soil samples by using the water quantity at OMC in order to obtain the ultimate dry density and then compare them to the standard soil materials that have already been tested. The standard used for testing is ASTM D 1883-99. For CBR Test Method, the compaction strength %CBR generally uses compact strength at the ratio of 0.1-inch depth [14, 15].

3. Research Methodology

The information of reclaimed asphaltic concrete used in testing was obtained from the Department of Highways, Songkhla Province. The asphalt passing the digestion was brought to be exposed to the sun to prepare for the further compaction process, as shown in Fig. 3.

Fig. 3. Reclaimed asphalt concrete used for testing.

The compositions were determined by testing reclaimed asphalt pavement materials, and reclaimed asphalt pavement materials mixed with cement and rubber were designed to conduct the experiment by preparing and testing 24 UCS samples and 8 CBR samples totaling 32 samples. The procedures of research study were conducted according to the plan as shown in Fig. 4.

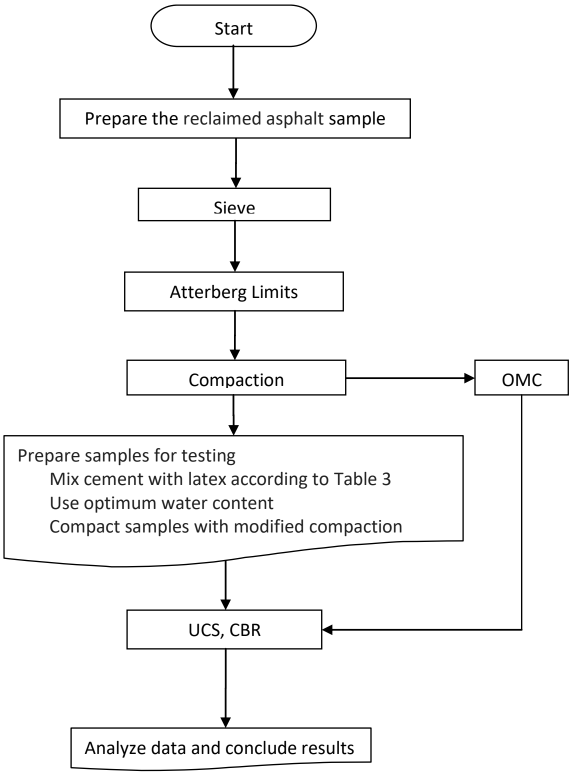

Fig. 4. Flow chart of experiment to find optimum amount of added NRL and cement.

3.1. Road Material Mixing in the Laboratory

Sample preparation for testing was be conducted using the reclaimed asphalt concrete samples that had been finely crushed and modified through compaction by ASTM D 1557 using a 2 inch diameter (30 cm), 4 inch (10 cm) height mold, and a 2.78 pound hammer (1262.10 g) with a12 inch (30 cm) lifting distance. The samples were divided into 5 layers which were compacted 25 times each. Under equal power in compaction, the samples received equal compact energy. The samples used comprised reclaimed asphalt concrete, rubber and cement: Portland cement type 1, of 3%, 5% and 7%, by the weight of reclaimed asphalt concrete (3000 g) was used. The total mixing was done under the Optimum Moisture Content, OMC. The finished samples were wrapped with a plastic sheet for preservation to prevent moisture from evaporating and stored in a container with a lid for moisture control. The samples were cured for 7, 14 and 28 days respectively with regards to the mixture rate and the number of samples.

3.2. Modified Proctor Compaction Test

Test Number DH-T 108/1974 Standard and AASHTO T 180 were used to find the relationship between soil density and the amount of water used for modified compaction when grinding in a mold using a hammer weighing 4.537 kg (10.0 lb). The falling distance of the hammer was 457.2 mm (18 inches) as shown in Fig. 5.

Fig. 5. Sample preparation features before testing.

3.3. California Bearing Ratio (CBR)

This test had been conducted according to ASTM D 1883-99 (Fig. 6) using the Modified Proctor method to test all soaked samples. To prepare the samples, the equipment consisted of; a 6-inch (15.2 cm) diameter, 7-inch tall mold, a 2-inch tall collar, and a punched base plate which the mold could be attached at both ends, a perforated base plate, a spacer disc, and a metal round steel sheet measuring 5 inches in diameter with a height of 2.4 inches placed on its one side with a drilled hole with a hand screw for easier removal in case it gets stuck in the mold. A compaction hammer weighing 5.5 pounds with a falling distance 12-inches for standard compaction, and a 10-pound compaction hammer with 18-inch falling distance for modified compaction was used (Fig. 7).

Fig. 6. California Bearing Ratio Test (CBR).

Fig. 7. Sample Placement and Various Sets of Composition Equipment before testing.

3.4. Unconfined Compression Test

According to STANDARD TESTING (105 DH.-T) and AASHTO T208 equivalent, Unconfined Compression Test (Fig. 8) is a testing method routinely employed for determining shear strength of a sample due to both being economical and easy to use. The cured compacted samples soaked in water for about 2 hours and were then removed. After removing the samples, they are weighed and measurements taken of diameter and height. The process of measuring is repeated after curing time lapses of 7, 14, and 28 days.

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Fig. 8. Unconfined Compression Test.

4. Results and Discussion

Based on the studied sample of the reclaimed asphalt concrete surface at Khlong Wa intersection, Hat Yai district, Songkhla province, the results were as follows:

4.1. Unconfined Compression Test

From Table 3 as an example, it can be observed at the end of the 7-day curing period that increasing the amount of cement results in increasing unconfined compressive strength. It is found that at the end of a 7-day curing period, 7% cement content acquires unconfined compressive strength of 70.47 ksc.

Table 3. UCS Test Results of the mixture for different percentage of cement content.

Test no.	% Cement	Average UCS (ksc)		
		7 days	14 days	28 days
1	3	19.34	21.75	22.24
2	5	45.28	52.48	60.23
3	7	70.47	93.54	100.48

4.2. California Bearing Ratio Test

Table 4. CBR test results of the mixture for different percentage of cement content at 7 days.

Test no.	% Cement	%CBR
1	3	40
2	5	54
3	7	82

Table 4 shows the CBR test results of the mixture for various cement after a 7-day curing period. The mixture achieved a maximum CBR value of 82 at 7% cement composition.

Table 5. Test Results of the mixture for various Cement and NRL contents.

Test no.	% Cement	%NRL	Average UCS (ksc)			%CBR
			7 days	14 days	28 days	7 days
1	3	5	14.53	19.76	26.72	38
2	3	10	11.05	16.68	22.56	33
3	3	15	3.56	5.04	6.34	28
4	5	5	22.09	25.46	28.42	40
5	5	10	20.77	24.67	28.44	35
6	5	15	10.22	13.45	18.24	32
7	7	5	23.89	28.72	33.52	42
8	7	10	21.40	24.24	28.31	40
9	7	15	16.46	19.42	25.65	34

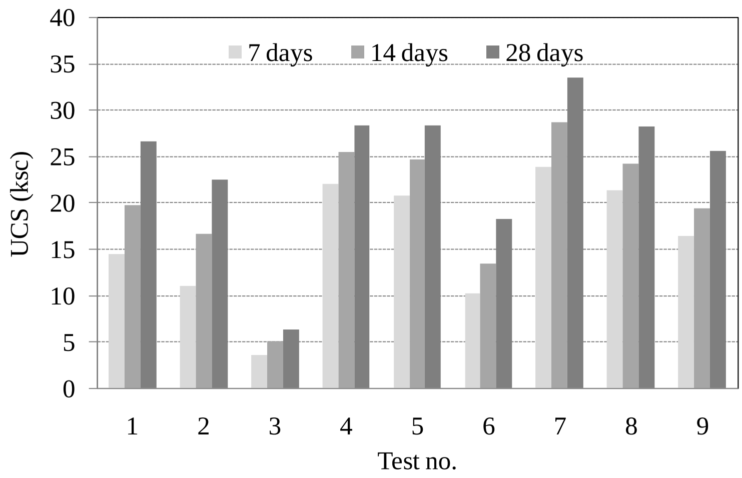

Fig. 9. UCS test results of the mixture for various Cement and NRL contents.

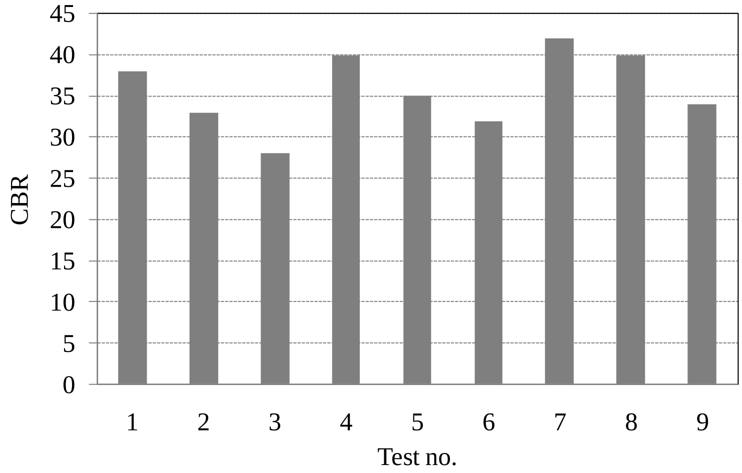

Fig. 10. CBR test results of the mixture for various Cement and NRL contents.

From Table 5 and Fig. 9, the mixture with NRL and cement shows that at 7 days curing period, 5% NRL and 7% cement (Test no. 7) gives the maximum CBR value of 23.89. From the analysis of %CBR and the amount of cement, it was found that the increasing cement content would increase %CBR value. From %CBR results, it was found that it is a good criterion which has tendency in the same direction as UCS value with the tested mixture exhibited two maximum values (see Fig. 10). In the set 1 test, it is the mixture of Asphalt concrete and 7% cement (Table 4). For the set 2 test, it is the mixture of Asphalt concrete mixed with 7% cement, and 5% NRL. Thus, it can be seen that NRL has great potential to be used for road construction in base course layer, and subbase course layer which consume a large quantity of NRL.

5. Conclusions

From the test results of various combinations of the mixture of reclaimed asphaltic concrete and cement, it was found that the value of Unconfined Compression Strength increases with increase in cement content. Test results for combinations of mixture of reclaimed asphaltic concrete, cement and NRL (Fig. 9) showed that increasing the amount of NRL beyond a certain value resulted in reduced compressive strength. Analysis of effect of cement content on compressive strength showed that an increase in cement content results in corresponding increase in compressive strength. Additionally, the mixture of asphaltic concrete and cement as specified in a DOH Standard governing the value of UCS materials used for base course, must have a UCS value greater than 17.5 ksc. From our results, it was possible to use the NRL added mixture in commercial applications. However, a significant issue was whether that Compaction and Mixing of the materials could meet specified standard, which could be determined by the availability of heavy machine needed to do the job. In terms of construction cost and environmental issues, the use of NRL added RAP is more advantageous when compared with conventional materials because stone aggregates or lateritic soil are obtained through demolishing of mountains which are becoming scarce and facing opposition from the locals. Thus, onsite recycling of pavement materials by adding NRL and cement is aviable alternative way to reduce the problem of getting rid of old pavement material and shortage of rocks.

The result of California Bearing Ratio tests showed that when cement content increased, the value of CBR also increased. For the mixture of reclaimed asphaltic concrete, cement and NRL, the results showed that as the amount of NRL increased, the value of %CBR decreased. The effect of cement content on %CBR was such that increasing amount of cement resulted in corresponding increase in the %CBR value. From CBR test results, a positive correlation between UCS value and mixture combinations was observed with the tested mixture exhibited two maximum values. In the set 1 test, it was the mixture of RAP and 7% cement. For the set 2 test, it was the mixture of RAP with 7% cement, and 5% NRL. Thus, it can be concluded that NRL has great potential to be used in road construction in both the base course and subbase course

In terms of cost, when compared with using the conventional road building materials such as crushed rocks, the NRL modified RAP is viable. The results of this research show that the cost reduction comes in the form of significant saving of resources by using renewable materials, reducing environmental impact from rock quarrying, and reducing the accident risks from trucks transporting waste materials away. However, for the cost comparison between (1) reclaimed asphaltic pavement mixed with cement and (2) reclaimed asphaltic pavement mixed with cement and NRL, the issue of long term durability needs to be further investigated as the cost of pavement would depend on the cost of rubber. However, the economic and financial benefits to Thailand and rubber farmers make it worthwhile to use this NRL modified RAP for road construction and maintenance.

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