Utilization of Waste Plastic Bags to Improve Stability of Para-Asphalt Concrete : A Case Study of the Entrance Road at Ao Nang Subdistrict Administration Organization, Krabi Province

Wechsawan Lakas

Department of Construction Engineering Technology, Faculty of Science and Technology, Chiang Mai Rajabhat University, Chiang Mai 50300

Corresponding author. E-mail address: wechsawan_lakas@hotmail.com

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Abstract

Utilization of waste plastic bags as an admixture to enhance the stability of para-asphalt concrete is a part of integrated solution to the problem of the continuous dropping of prices of natural rubber, a crisis for the rubber production industry, and the environmental crisis of accumulated plastic waste. The target community was Ban Thung Village, Moo 5, Tambon Ao Nang, Muang District, Krabi Province. The process started from sorting out wastes to construct a prototype road for the community. It is found from this investigation that the community was able to segregate 200 kg of plastic bags, accounting to 1.83% of the total waste generated. These bags were then mixed into para-asphalt concrete in the laboratory and tested for its stability by the Marshall Test. It is revealed that the concrete samples with a 10% mixture of the waste plastic bags by weight of the para-asphalt concrete have the stability of 13.7 kN, which is higher than the 12.7 kN of regular para-asphalt concrete and 9.8 kN of the standard criterion specified by the Department of Highways. The concrete is able to be used for constructing a road or an activity field in the community by mixing 5 mm waste plastic bags into the asphalt concrete while surfacing the road. The temperature of the concrete should be higher than 140°C in order for the plastic to fully melt into the concrete. The road surface is then pressed solidly and open for public use.

Keywords: Para-Asphalt Concrete, Natural Rubber-Modified Asphalt Concrete, Waste Plastic Bags

Introduction

Para-asphalt concrete has better stability and can bear a heavier traffic weight than regular asphalt concrete. Furthermore, it is better resistant to rutting, has longer duration of use, and can better reduce maintenance costs during its use (Bureau of Maintenance, 2016). More importantly, it helps promote the domestic para-rubber consumption according to the state policy. In the past, several state agencies have incorporated para-rubber into road construction. The Department of Rural Highways has constructed para-asphalt concrete and para-slurry seal roads from 2013 to 2016, accounting for 15,487 tons of raw para-rubber and 7,744 tons of concentrated latex. Additionally, the Department of Highways Thailand (2013) conducted a job mix formula comparison of para-asphalt concrete in the laboratory and implemented the results by constructing a test concrete in the office of Nakhon Nayok Provincial Bureau of Maintenance. It was found that the stability of the 5% para-asphalt concrete was 13 kN, slightly higher than the 11.60 kN stability of a regular asphalt concrete. The pre- and post-construction assessment of the concrete performance revealed that the skid resistance value of the para-asphalt concrete was better than that of a regular asphalt concrete with less permanent wear and more resistance to rutting. Furthermore, it could better tolerate heavy traffic weight, enabling motorists to use the roads more safely.

The incorporation of para-rubber to improve asphalt cement properties for road construction in Thailand has been conducted for over 60 years. Initially, the experiment mixed 5% of the para-rubber solution with the asphalt cement to construct the Hat Yai- Song Khla highway (Vichitcholchai & Na Wichien, 2013). From the visual inspection, the highway was in good condition without damage from regular traffic use. In 2003, the Rubber Authority of Thailand in collaboration with King Mongkut's Institute of Technology Ladkrabang conducted a study to improve asphalt properties with natural rubber by mixing finely ground smoked rubber sheets with asphalt cement at the ratios of 4%, 5%, 6% and 7%. It was found that the mixture at the ratios of 4%, 5% and 6% passed the asphalt standards of the 851-2532 Thai Industrial Standard specifications, except that of 7%. In 2004, a research team from the Department of Agriculture constructed an asphalt cement para-rubber solution mixing prototype machine for a pilot project to construct para-asphalt concrete road in 35 areas under the supervision of the Department of Agriculture (Plastic Institute of Thailand, 2016). It was found that the utilization of the road was normal with better fatigue resistance, permanent damage resistance and rutting resistance values than regular asphalt concrete roads. After that, an asphalt cement-dry para-rubber mixing prototype machine was further developed for use at the commercial industry level. It was revealed that the prototype roads were in good condition with rutting resistance as high as 2.9 times and with an expenditure increase of merely 15-20% (Way et al., 2013; Krishnapriya, 2015).

In addition, there have been studies to improve the quality of para-asphalt concrete by mixing PE, PP and PS plastic waste into the para-asphalt concrete at 5% to 20% by weight of the cement. They are mixed at 160-180°C until they are completely melted and blended. The mixture is Marshall tested and it is found that the Marshall stability is higher than the regular asphalt concrete. Furthermore, its other properties are in line with the highway engineering standards, which can be applied to construct roads for regular traffic use (Vasudevan, Ramalinga Chandra Sekar, Sundarakannan & Velkennedy, 2012; Ahmadinia, Zargar, Karim, Abdelaziz & Shafigh, 2011). In Thailand, the first study on the construction of a plastic-mixed asphalt concrete road was conducted in Chiang Mai by Lakas, Setthapun & Lucksiri (2017). The LDPE plastic derived from the target communities for 4,757.3 kg was added to the asphalt concrete at the ratio of 21.9% by weight of asphalt cement. The mixture was then paved on the one-kilometer road surface at the entrance of the Asian Development College for Community Economy and Technology, Chiang Mai Rajabhat University. It was found that the stability of the road was as high as 13.4 kN. After the road had been open for traffic use for five years, it was still in good condition (Lakas et al., 2017). There have been no previous studies on adding waste plastic bag to increase the stability of para-asphalt concrete. For this study to be congruent with its objective and direction, two research hypotheses are proposed. Firstly, plastic bag waste is capable of enhancing the stability value of para-asphalt concrete; and secondly, the construction of a prototype para-asphalt concrete road can reduce the quantity of plastic bag waste in the target community.

Research methodology and instruments

This research project is an innovative construction of natural rubber asphalt concrete (para-asphalt concrete) with quality improvement from added plastic bag waste. The aims are to reduce amounts of plastic bag waste and to promote domestic consumption of para-rubber. There are two variables in this study.

1. The independent variables include a quantity and types of plastic bag waste collected at Ban Thung Village and its neighborhood in Tambon Ao Nang, Muang District, Krabi Province; natural rubber modified asphalt (NRMA) without foreign substances besides less than 5% of natural rubber quantity by weight and without disintegration at 170 °C or after cooling as well as other properties specified in the DS-H 409/2556; and aggregates in the provincial area with their properties specified by the Department of Highways.

2. The dependent variables are highway engineering properties, including density, air void, the Marshall stability and flow values, as shown in Table 1. Other properties are in accordance with the standard specifications of NRMA at DS-H 416/2556 of the Department of Highways.

Table 1 Fundamental standard properties of NRMA

For the 9.5-mm wearing course	
Density	> 98% of laboratory density
% Air Void	3% - 5%
Marshall Stability (kN)	> 9.8 kN
Flow 0.25 mm. (0.01″)	2.25 mm. - 4.25 mm.

Steps of the research methodology are as follows.

1. Survey the types and quantity of overall waste in the target community and its neighborhood. After that, plastic bag waste was separated from other types of waste with collaboration from the local residents. The plastic bag waste is used as an additive to improve the stability of the para-asphalt concrete.

2. Design the job mix formula in the laboratory by means of the Marshall method. Fifteen cylindrical samples with 4 inches in diameter and 2.5 inches in height were constructed. The samples were divided into five sets with each set containing three samples. Each set was composed of aggregates with 3/8”, 1/2” and 3/4” in size and stonedust at the ratio of 42 : 25 : 18 : 15 by weight. The different quantity of para-asphalt cement in each set was 4.5, 5.0, 5.5, 6.0 and 6.5 by weight of the aggregates. The preparation and test of the samples were conducted according to the test standard at DS-H 416/2556 of the Department of Highways.

3. Test the samples by using the Marshall Testing Machine and calculate for an appropriate ratio between the aggregates and percentage of para-asphalt cement in order to design the mixture of plastic bag waste-added para-asphalt concrete.

4. Construct plastic bag waste-added para-asphalt concrete samples based on the results in 3. The plastic bag waste was shredded into the 5-mm size and mixed into the para-asphalt concrete with an equal amount of aggregates and para-asphalt cement. There were 18 samples divided into six sets with each set consisting of three samples. The quantity of the plastic bag waste was 0, 5, 10, 15, 20 and 25% by weight of the asphalt cement.

5. Carry out the test of the samples in order to find out the highway engineering properties, which include density, air void, the Marshall stability and flow values. The appropriate mixture derived from this test was to be used in the construction of the prototype road in the study area.

6. Construct a plastic bag wasted-added para-asphalt concrete road in the study area. The waste collected from the target community was used to enhance the stability of the para-asphalt concrete road and it was open for actual public use.

Research results and discussion

The results of the investigation on utilizing plastic bag waste to enhance the stability of para-asphalt concrete can be elaborated into three areas. They include types and quantity of plastic bag waste collected from the target community during the study period; a comparison of highway engineering properties between regular and plastic bag waste-added para-asphalt concrete; and the construction of the plastic bag waste-added para-asphalt concrete road in the target community.

1. The investigation on the types and quantity of plastic bag waste at the target community from December 2016 to March 2017 by means of participative observation revealed that there were 1,776 residents in 1,309 households in the community. The waste generated within the community was approximately 3,000 kg per day (1.9 kg/person/day or 2.29 kg/household/day on average). The waste was divided into 2.7% hazardous waste, 8.1% recyclable waste, 2.7% garbage and 86.5% general waste. The generated waste was correctly managed by separating recyclable waste for sale and organic waste for producing effective microorganism fertilizers. Nevertheless, there had been a certain amount of plastic bag waste that was not separated from the overall waste. To obtain the required quantity of plastic bag waste, a campaign to segregate plastic bag waste from home was launched. This type of waste can be used to construct a road or an activity ground in the community. After the campaign launch, 40 households participated in the plastic bag waste segregation from home and 200 kilograms of the waste were obtained, averaging 0.042 kg/household/day. It accounted for 1.83% of the overall waste generated in the community, as shown in Figure 1.

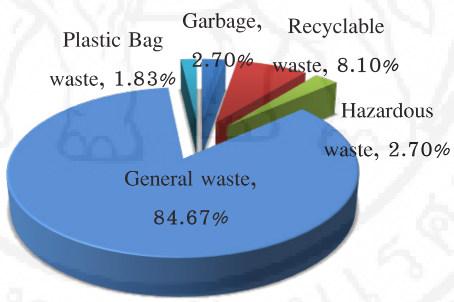

Figure 1 Quantity of waste in the target community from December 2016 to March 2017

2. The comparison on highway engineering properties of regular and plastic bag waste-added para-asphalt concrete started from laboratory testing by the Marshall method of the regular para-asphalt concrete with 5% natural rubber modified asphalt cement mixed with 3/8", 1/2" and 3/4" aggregates and silt stone with the ratios of 42 : 25 : 18 : 15 by weight. It is found that 4% air void of para-asphalt concrete yields 5% quantity of working para-asphalt cement, resulting in 12.68 kN stability, 3.30 mm. flow values and 2.469 density. The values are within the standards at DS-H 416/2556 of the Department of Highways.

Figure 2 The laboratory mixture of plastic bag waste with para-asphalt concrete (left: added shredded plastic bag waste to aggregate; center: mixing shredded plastic bag waste with aggregate; right: added para-asphalt cement to mixture)

The plastic bag waste-added para-asphalt mixture in Figure 2 with different proportions of the waste at 0, 5, 10, 15, 20 and 25% by weight of the para-asphalt cement was tested in the Marshall Testing Machine for its density, air void, stability and flow values. The test results are as follows.

Density of the para-asphalt mixture varies according to the quantity of the added plastic bag waste, as shown in Figure 3. When the plastic bag waste is added from 0%, 5%, 10%, 15%, 20% to 25%, the density of the para-asphalt mixture decreases to 2.469, 2.459, 2.450, 2.442, 2.434 and 2.423, respectively. The downward trend continues with additional plastic bag waste or over 98% of the regular para-asphalt concrete at 25% of the waste quantity. This is because the added waste is of LDPE type with the density from 0.92 to 0.94, whereas para-asphalt cement is of AC 60/70 mixed with natural rubber with the density of 1.02. Consequently, when more waste is added, the overall density of the para-asphalt mixture decreases accordingly.

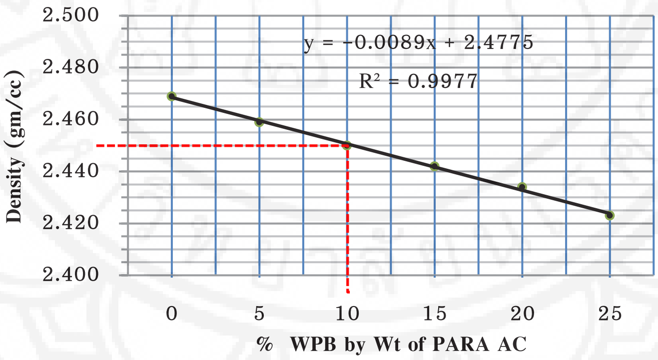

Figure 3 Density values and quantity of plastic bag waste added to the para-asphalt concrete

Air void varies according to the quantity of the added plastic bag waste, as shown in Figure 4. It is seen that the higher percentages of the quantity of the waste continuously increase the air void values of the para-asphalt mixture to 4.1%, 4.4%, 4.7%, 5.1%, 5.4% and 5.8%, respectively. The upward trend continues to increase higher than the test standard of the Department of Highways, which is designated at the 3% - 5% range only.

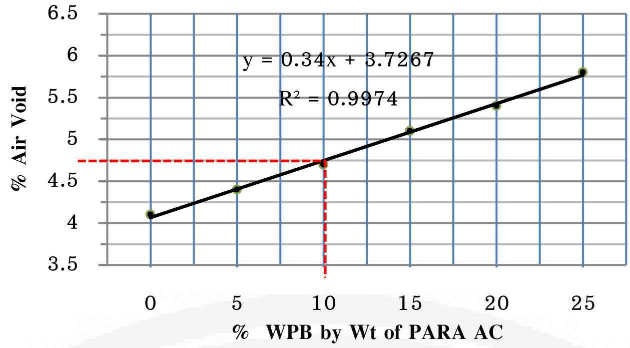

Figure 4 Air void values and quantity of plastic bag waste added to the para-asphalt concrete

The Marshall stability values of the plastic bag waste-added para-asphalt concrete increase in accordance with the quantity of the added waste, as shown in Figure 5. It is found that, when mixing 25% of the waste by weight of para-asphalt cement, the stability value is as high as 14.5 kN, higher than the 12.7 kN stability value of regular para-asphalt concrete and higher than the 9.8 kN stability value specified by the Department of Highways (DS-H 416/2556).

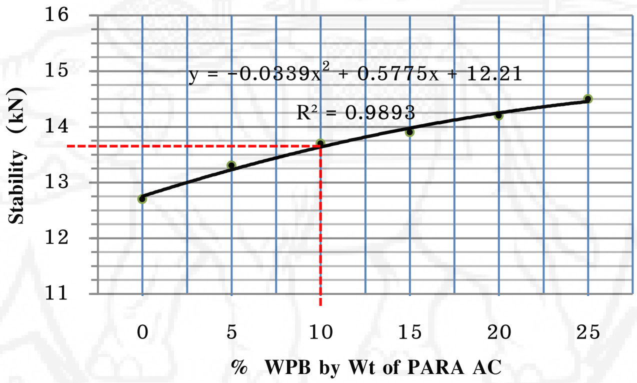

Figure 5 The Marshall stability values and quantity of plastic bag waste added to the para-asphalt concrete

Flow values are tested in the Marshall Testing Machine in simultaneity with the Marshall stability values. Both flow and stability values vary according to the quantity of the added plastic bag waste, as shown in Figures 5 and 6. It is seen that the higher percentages of the quantity of the waste continually increase the flow values of the para-asphalt mixture to 3.3, 3.6, 3.8, 4.1, 4.3 and 4.6 respectively. Figure 6 indicates that the flow values of the para-asphalt concrete with 5-20% added quantity of plastic bag waste are still in the standard ranges of 2.25 mm to 4.25 mm designated by the Department of Highways.

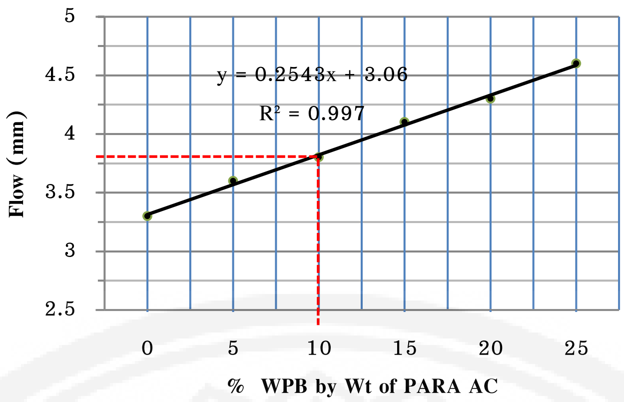

Figure 6 Flow values and quantity of plastic bag waste added to the para-asphalt concrete

3. The study results in 1 and 2 are incorporated to construct a prototype road around the activity ground at Ao Nang Tambon Administration Organization. Of the total area of 1,200 square meters, 334 square meters were allocated for the construction of the prototype road with the thickness of 5 cm. The construction materials were as follows.

- Two tons of para-asphalt cement (mixing 5.0% of the para-rubber solution by weight of AC 60/70 asphalt cement)
- The mixed proportion hot bin (42:25:18:15), 16.8 tons of 3/4" stone, ten tons of 1/2" stone, 7.2 tons of 3.8" stone and 6 tons of silt stone
- 200 kg of plastic bag waste collected from the target community (10% by weight of para-asphalt cement)

The steps of constructing a plastic bag waste-added para-asphalt concrete road are the same as those of constructing a regular road. It starts from ground leveling, ground compacting, base work, sub-base work to prime coat. The difference is at the surface treatment, where 5 mm pieces of plastic bag waste are mixed into the concrete at the right quantity found in the laboratory test. It is 10% by weight of para-asphalt cement, as shown in Figures 3-6, or about 200 kg in the paving machine, as shown in Figure 7, or mixing them into the hot mixture using human labor in case of machine failure, as shown in Figure 8. The cautions are that the waste pieces must be spread evenly and the temperature of the para-asphalt concrete during the construction must not be lower than 140°C in order for the added plastic bag waste to completely melt with the concrete. The mixture must be evenly spread at the thickness of 5 cm and then compacted by a road roller. The density during the compact must not be lower than 98% of the laboratory density, as shown in Figure 3. After the completion of the construction, the road was open for regular traffic use. A drill investigation after opening for public use revealed that the density of the road was 2.454, higher than the 2.450 density value in the laboratory at the 10% mixture of the plastic bag waste.

Figure 7 Mixing plastic bag waste with a paving machine

Figure 8 Mixing plastic bag waste with workers

Discussion

The target community and its neighboring areas have a socio-economic structure conducive to rapid economic growth, for there are many nearby tourist attractions popular among local and international tourists, such as, Ao Nang, Nopharat Thara and Rai Lay beaches. There have been several public service agencies in the area, for instance, Ao Nang Tambon Administration Organization, mosques, temples, and two local state-run schools. As a consequence, on average, each individual generated 1.69 kg of garbage per day, higher than the national rate of 1.14 kg/person/day (Pollution Control Department, 2017). The Tambon Administration Organization has launched a monthly campaign on "Big Cleaning Day" to initiate public awareness of business operators, local residents and youths on keeping their community clean and classifying garbage types.

Besides hazardous, recyclable and general garbage that needed to be disposed of, recycled plastic bags could be separated, accounting for 1.83% of the total garbage. These recycled plastic bags can be utilized to improve and enhance the stability values of para-asphalt concrete. These findings confirm the study results of Vasudevan et al. (2012) in that adding PE, PP and PS plastic waste into asphalt concrete increases the stability values to 18-20 kN. For the density, it is found that designing the mixture of regular para-asphalt concrete, the density value tends to be higher when more para-rubber is added. Nonetheless, the density value decreases when plastic bag waste is added, because when LDPE plastic waste with its density between 0.92 and 0.94 is added into para-asphalt cement with its density between 1.00 and 1.05, the density value of the surface mixture tends to decrease. Air void values are in contrast with regular para-asphalt concrete, which are lower when more para-rubber is added. However, when plastic bag waste is added, air void values tend to be higher due to continuously lower density. The flow values are in line with the highway engineering standard if the quantity of added plastic bag waste does not exceed 20%. From Table 2, it is found that the maximum quantity of plastic bag waste added into para-asphalt concrete without changing its highway engineering properties is 13% by weight of para-asphalt cement. If more is added, the first changed property is the air void value that exceeds 5%, resulting in the air void values higher than what is specified and an opportunity for damage due to water seepage as well as ensuing surface damage. The second changed property is the flow value to exceed 4.24 mm, resulting in the road being permanently damaged and not returning to the original form after being suppressed by heavy traffic weight. In the long term, rutting appears and surface damage ensues.

Table 2 Comparison of plastic bag waste quantity and fundamental standard specifications of para-asphalt concrete

	Quantity of plastic bag waste	0%	5%	10%	15%	20%	25%
Density	> 98%						
% Air Void	3% - 5%						
Marshall Stability (kN)	> 9.8 kN						
Flow 0.25 mm. (0.01″)	2.25- 4.25						

Plastic bag waste used in the construction process of the prototype road is simple to do without requiring any complicated steps or technology. However, the temperature must be controlled to stay over 140°C in order to evenly melt the waste. The waste can be added into para-asphalt cement or para-asphalt concrete in the factory or at the construction site, depending on the size and quantity of the construction (Lakas et al., 2017).

Conclusion and recommendation

Plastic bag waste collected and sorted out at the target community is no longer the garbage waiting to be disposed. It can currently be reused to enhance the stability of para-asphalt concrete road. This experiment was conducted by constructing a prototype road around the activity ground at the Ao Nang Tambon Administration Organization, covering an area of 334 square meters with the thickness of 5 centimeters. It took four months for the community to sort out the plastic bag waste that yielded 200 kg or 1.83% of the total generated waste. The waste as an additive was then shredded into 5-mm pieces and mixed into the para-asphalt concrete during the construction at approximately 10% by weight of para-asphalt cement. The temperature must be controlled to be over 140°C and the stability of the road is as high as 13.7kN, higher than the 9.8kN required by the standard of the Department of Highways. The findings confirm both hypotheses of the study in that plastic bag waste is able to increase the stability value of para-asphalt concrete and the construction of a plastic bag waste-added para-asphalt concrete road can reduce the quantity of plastic bag waste in the target community. From Figures 3-6, it is seen that as much as 12.5% of the waste by weight of para-asphalt cement can be added. However, the flow values and air void tend to exceed the requirements established by the Department of Highways. The results are that the road becomes rigid and fragile, being susceptible to permanent deformity and resulting in damage faster than its expected duration of use.

The study results can be applied in the construction of roads in other areas nationwide by enhancing the stability of para- asphalt concrete, particularly communities cultivating para- rubber plants as an economic crop and having currently encountered the price drop problem of the rubber. Furthermore, the results can be applied with regular asphalt concrete in an attempt to reduce the plastic waste problem in the community. The endeavor would yield environmentally friendly roads with collective participation of community members, empowering their respective communities and increasing their quality of life. Moreover, it promotes more domestic consumption of rubber and sustainably solves the problem of plastic waste. For further studies, it is recommended that there should be experiments on different methods of mixture. For instance, plastic bag waste is added to para-asphalt cement before mixing with factory aggregates with steady temperature control to achieve completely melted wastes and evenly-blend with the cement.

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References

Ahmadinia, E., Zargar, M., Karim, M. R., Abdelaziz, M., & Shafigh, P. (2011). Using waste plastic bottles as additive for stone mastic asphalt. *Mater. Design*, *32*, 4844-4849.

Bureau of Maintenance. (2016). *Annual Report 2016 Bureau of Maintenance*. Bangkok: Department of Rural Roads.

Department of Highways Thailand. (2013). Road Prototype Research of Para Asphalt Concrete. *Executive Summary Report*, N.P.: n.p.

Krishnapriya, M.G. (2015). Performance Evaluation of Natural Rubber Modified Bituminous Mixes. *Journal of Civil, Structural, Environmental, Water resources and Infrastructure Engineering*, *5*, 1-12.

Lakas, W., Setthapun, W., & Lucksiri, K. (2017). Process of Asphaltic Concrete Pavement Construction to Reduce Plastic Waste Problems in the Community. *Academic Journal Uttaradit University*, *12*(1), 41-53.

Plastic Institute of Thailand. (2016). *Use of Natural Rubber for Road Construction and Maintenance*. Retrieved from http://rubber.oie.go.th/box/Article/46746/

Pollution Control Department. (2017). *A situation report of Municipal Solid Waste in Thailand 2016*. Retrieved from http://www.pcd.go.th/public/Publications/print_report.cfm?task=wsthaz_annual59.

Rubber Authority of Thailand. (2017). Retrieved from http://www.rubber.co.th/rubber2012/menu5.php

Vasudevan, R., Ramalinga Chandra Sekar, A., Sundarakannan, B., & Velkennedy, R. (2012). A technique to dispose waste plastics in an ecofriendly way – Application in construction of flexible pavements. *Construction and Building Materials*, *28*, 311–320.

Vichitcholchai, N., & Na Wichien, A. (2013). The use of Para Rubber Mixed Bitumen. *Para Rubber Electronic Bulletin*, *15*, 18-24.

Way, G. B., Biligiri, K. P., Kaloush, K., Sousa, J., Pinto, A., & Cao, R. (2013). Review of International use and Technology of Asphalt Rubber Open Graded Friction Course Mixes. *International Journal of Pavements Conference, São Paulo, Brazil*, *140*(1), 1-9.