

กระบวนการสร้างถนนแอสฟัลติกคอนกรีต เพื่อลดปัญหาขยะพลาสติกในชุมชน

05

Process of Asphaltic Concrete Pavement Construction
to Reduce Plastic Waste Problems in the Community

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บทคัดย่อ

งานวิจัยนี้เป็นการศึกษากระบวนการสร้างถนนแอสฟัลติกคอนกรีตด้วยขยะพลาสติกที่ได้จากการคัดแยกขยะภายในชุมชนมหาวิทยาลัยราชภัฏเชียงใหม่และพื้นที่ข้างเคียง แล้วนำเอามาเป็นส่วนผสมเพิ่มความเสถียรภาพให้กับถนนแอสฟัลติกคอนกรีต โดยเอาขยะถุงพลาสติกที่คัดแยกได้มาตัดเป็นชิ้นเล็กๆ ผสมกับวัสดุมวลรวมละเอียดและยางแอสฟัลต์ซีเมนต์โดยใช้ความร้อน แล้วนำไปทำเป็นก้อนตัวอย่างเพื่อทดสอบหาคูณสมบัติทางวิศวกรรมในห้องปฏิบัติการโดยวิธีมาร์แชลล์ (Marshall Test) จากนั้นหาส่วนผสมที่เหมาะสมที่สุดตามเกณฑ์มาตรฐานของกรมทางหลวงเพื่อนำไปใช้ในการก่อสร้างถนนต้นแบบภายในมหาวิทยาลัยราชภัฏเชียงใหม่

จากผลการทดลองพบว่าขยะถุงพลาสติกสามารถเพิ่มความเสถียรภาพของถนนแอสฟัลติกคอนกรีตได้สูงถึง 13.4 kN สูงกว่าถนนแอสฟัลติกคอนกรีตธรรมดาที่มีค่าเสถียรภาพเพียง 10.6 kN และสูงกว่าเกณฑ์มาตรฐานของกรมทางหลวงที่กำหนดค่าเสถียรภาพไว้ต้องมากกว่า 8.0 kN และที่สำคัญยังทำให้ชุมชนในพื้นที่เป้าหมายลดปริมาณขยะถุงพลาสติกได้มากถึง 4,775.3 kg นอกจากนี้ยังได้ขยายผลงานวิจัยไปสู่ชุมชนเป้าหมายที่มีศักยภาพในการนำไปใช้ประโยชน์สูงสุดทั้ง 4 ภูมิภาคในประเทศไทย

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Abstract

This research investigates asphaltic concrete pavement construction process using plastic wastes which were collected from Chiang Mai Rajabhat University and its neighborhood as an additive. A Job Mix Formula for a regular mixture was established and used as a basis for the design of modified asphaltic concrete samples in which different amount of plastic wastes were added. Marshall Method was used to determine strength and deformation properties of the samples. The specified requirements of Thailand's Department of Highways were used as a benchmark. The obtained optimum plastic waste content was selected and implemented on a road construction at the Chiang Mai Rajabhat University.

The study results have shown that adding an appropriate amount of plastic wastes to the mixture is capable of increasing the stability value of the pavement to 13.4 kN compared to those of 10.6 kN from the regular mixture and 8.0 kN from Thailand's Department of Highways standards. An implementation to construct at Chiang Mai Rajabhat University have also shown that adding plastic wastes to asphaltic concrete mixture was able to reduce plastic wastes in the community by as much as 4,775.3 kg. In addition, the technology has also been transferred to the target communities with most potential in all four regions of Thailand.

Keywords: Asphaltic Concrete, Waste Plastic Bags, Bitumen, Pavement Design

Introduction

Plastic has been extensively used around the world to manufacture many kinds of products such as bottles, bags, appliances, automobile parts, or furniture. The benefits of plastic products include their light weight, durability, and lower cost relative to many other material types (Andrady & Neal, 2009). For decades, global consumption rate of plastics has been increasing each year. It was estimated that plastic production in 2013 was as much as 299 million tons, which is a 3.9% increase compared to that in 2012. With this massive amount of plastic used, it is essential to have effective, practical, and economical methods to manage waste plastic, which is made up around 10% of all solid waste (Barnes, Galgani, Thompson & Barlaz, 2009). Therefore, different methods of recycling and reusing waste plastics have been proposed by researchers as alternatives to traditional methods such as burning and disposing in landfills. Among these efforts, one application that has been introduced is to

use waste plastics as bitumen modifier in asphaltic concrete (AC) pavement where various study results have shown that waste plastics containing high density polyethylene (HDPE), low density polyethylene (LDPE), or Polyethylene Terephthalate (PET) can be a potential binder to improve engineering properties of asphaltic pavement (Ahmadinia, 2011) when added at an appropriate amount. Khan and co-workers reported the usage of waste plastic bags mixed in bitumen for road pavement could reduce the usage of bitumen up to 10% (Khan, 2010), i.e., approximately one ton of shredded waste plastic bags could be homogeneously mixed with aggregate at 160-170°C to produce a road with the dimension of 3.5 m in width and 1 km in length (with a thickness of 5 cm). Verma also indicated that an addition of 3-4% of waste plastics to bitumen resulted in higher mechanical properties (Verma, 2008).

Implementation of the available knowledge can be beneficial for communities where waste plastic is an issue. Although the results from previous researches provide supports to application of waste plastics in AC pavement, there are some issues in regards to working process that, if clarified, would provide more understanding and, therefore, offer more options for implementation. This project was thus initiated to investigate the possibility of using different mixing processes of blending waste plastic bags to AC mixture. In addition, this investigation would focus not only on methods, but also actual implementation in field, starting from classifying plastic waste to on-site implementation. The cost of bitumen used for each method will also be compared. A case study to implement the obtained results will be presented and discussed.



Research Objectives

- 1) To investigate the production process of WPB-mixed asphaltic concrete pavement
- 2) To construct a prototype of WPB-mixed asphaltic concrete pavement in the communities



Scopes of Study

Two basic approaches to mix waste plastic bags (WPB) to AC mixture included in this study were adding approach (Approach A) and replacing approach (Approach B). For the adding approach, WPB were added in addition to the designed amount of bitumen. This approach is simple since it requires no adjustment to the designed amount of bitumen. For

the replacing approach, some portion of the designed bitumen was replaced by WPB. This approach is conceptually more suitable for cases where reduction of bitumen cost is a major concern.

In regards to mixing process, three alternative ways to blend shredded plastics were included in this study which are (i) blending WPB to hot bitumen, (ii) blending WPB to hot aggregate, and (iii) spraying shredded plastics directly to hot-mixed asphaltic concrete at site. Therefore, approach A was classified into 3 groups which are A1 (Adding approach + blending WPB to bitumen), A2 (Adding approach + blending WPB to aggregate), and A3 (Adding approach +blending WPB to AC mixture). Similarly, Approach B was categorized into 3 groups including B1, B2, and B3.

Materials and mix design

Waste plastic bags used in this project were randomly collected from Rajabhat Chiang Mai University and its neighborhood area. It was found that the amount of WPB is approximately 9.14 kg/day which is about 1% of all the waste in the community. These bags were shredded into small pieces with their size ranges from 3-5 mm. No chemical process was used for the preparation of plastic waste. Bitumen used in this project was AC60-70 which is a typical grade used in Thailand. The dense-grade aggregate gradation is used in this study (Figure 1). The upper and lower limits are as specified by Thailand’s Department of Highways for heavy traffic pavements.

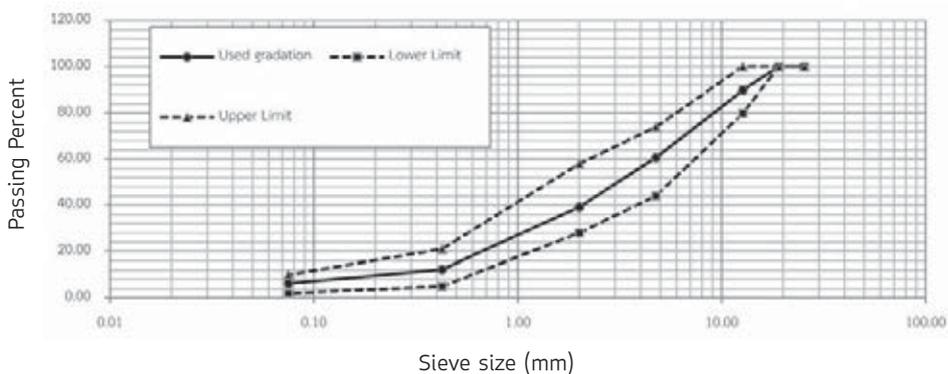


Figure 1. Particle size distribution for dense-grade aggregate used in this study

The mix proportion hot bin of the aggregates 3/4", 1/2", 3/8" and rock dust was 10:16:24:50 by mass. The regular (unmodified) AC mixtures were designed based on Marshall Method to achieve the specified requirements of Thailand's Department of Highways for heavy traffic pavement. The optimum bitumen content was found to be 5.2% and was used for this study.

Research Methodology

1) Effects of Mixing Concept and Mixing Method

Table 1 shows experimental plan for adding approach (Approach A) where samples were classified into three groups of different mixing methods (Method A1, A2, and A3). For each mixing method, WPB was blended into the mixtures at 5, 10, 15, 20 and 25% by weight of the design amount of bitumen. The limitation of maximum WPB content was based on the pilot test that specimens with WPB over 25% show obvious brittle behavior. A benchmark case with no WPB added was included to represent the conventional process. Three specimens were tested for each set. Experimental plan for Approach B was similarly set up, i.e. the mixing methods were classified into 3 groups including method B1, B2 and B3. As a result, a total number of 93 samples were included in this study.

Table 1. Experimental plan for adding approach (Approach A and B)

Mixing Concept	Adding Approach (Approach A)														
Mixing Method	Bitumen (Method A1)					Aggregate (Method A2)					AC Mixture (Method A3)				
WPB (%)	5	10	15	20	25	5	10	15	20	25	5	10	15	20	25
Number of Samples	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Mixing Concept	Replacing Approach (Approach B)														
Mixing Method	Bitumen (Method B1)					Aggregate (Method B2)					AC Mixture (Method B3)				
WPB (%)	5	10	15	20	25	5	10	15	20	25	5	10	15	20	25
Number of Samples	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

2) Determination of Maximum Amount of WPB

Pavement properties as specified by Thailand's Department of Highways for pavement are stability, flow and percent air void values. For flow values and percent air voids, the results obtained from this study were used without any modification. For stability values, a Student's t-distribution with a number of degrees of freedom (n-1) of 2 was assumed for each test set and the 95% lower one-sided bound was determined accordingly. These reduced

stability values were then used to compare to values specified by Thailand's Department of Highways. The maximum amount of WPB was the maximum content that the obtained AC specimens still meet all the requirements for heavy traffic pavement.

3) Implementation of Results

An implementation phase was set up in order to demonstrate how a community could make use of the proposed methods and results. In this study, activities were handled by two groups of volunteer which are (i) plastic waste collecting team and (ii) construction team. The plastic waste collecting team is responsible of collecting and analyzing the amount of plastic wastes produced from their own community. The amount of plastic bags then recorded and statistically analyzed to obtain the amount of waste plastic bags produced. This data will be beneficial for the community to develop their road construction plan as well as plastic waste management plan. The construction team is responsible for shredding WPB into the recommended sizes as well as distributing shredded waste plastic on to the asphaltic concrete mixture. The construction team could be a volunteer from either professional road builder or from the community.

Chiang Mai Rajabhat University community was selected as a pilot project this phase of study. Plastic wastes collection was carried out in the main campus area while road construction was carried out at Maerim campus. Subsequently, the implementation was extended to four major regions of the country which includes Chiang Mai (Northern), Samut Songkram (Central), Khonkaen (Northeastern), and Krabi (Southern).

Results and Discussion

Specimens produced by Approach A and B were tested in accordance with the specification of Thailand's Department of Highways. The results of the modified AC properties and the implementation phase are presented and discussed in this section.

1. Effects of Mixing Concept and Mixing Method

1) Air void. The relationship between average percent air void (AV) and WPB content for all test sets are as shown in Figure 2. It can be seen for all mixing methods that the average percent AV tends to increase as the WPB content increase. In regards of mixing concept, the average percent AV from Approach B (Replacing approach) are typically greater the those of Approach A (Adding approach) when compared at the same WPB content. This is because samples from Approach B contain less amount of hot bitumen as it was replaced by WPB, a lower density material. Method B2 (Replacing method-adding WPB to hot aggregate) and B3 (Replacing method-adding WPB to AC mixture) are the two methods that tends to

have higher percent AV increasing rate. This could be resulting from (i) the amount of hot bitumen was reduced and (ii) no heat was provided at the WPB mixing stage. Therefore, the shredded WPB for these two methods could possibly clump together and develop small pores, in the form of partly melted plastic. The occurrence of this situation could also depends on how well the WPB were distributed to the prepared materials.

For Approach A, it is possible to add WPB up to 17.5% according to the specified range of 3-5% AV of Thailand’s Department of Highways. The results exhibited are also in agreement with the result from El-Saikaly where 6-18% of WPB was used and the AV was in the range of 4.35-4.85%. For method B1 and B3, up to 10.8% of WPB can be added to the mixture. This is with the exception of B2 (adding WPB to hot aggregate) where WPB can be used up to only 3.6%.

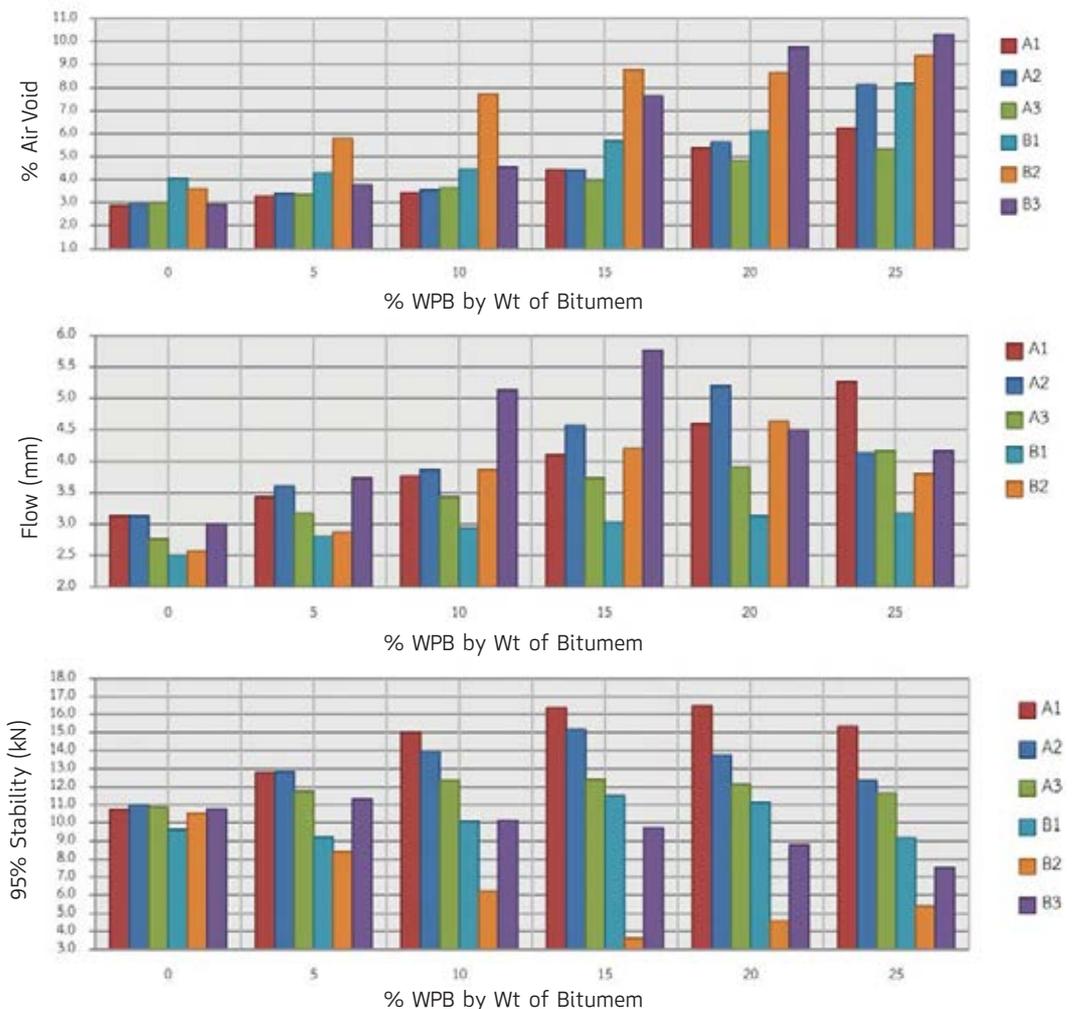


Figure 2. Relationship between air void, flow value, Stability value and WPB content

2) Flow value is the vertical deformation of the specimen measured at maximum load (stability value). While no obvious trend could be observed between flow values from Approach A and B, it was found that the average flow values of all test sets are higher than that of the conventional method (0% WPB content) (Figure 2) which represents that the specimens have sufficient binder and behave more plastically. In the range of 0-15% WPB, flow values for all test sets tend to increase with the increasing amount of WPB and % air voids. For WPB over 15%, flow values start to decline for some cases, i.e. method A2, B2 and B3, which means that excessive addition of WPB could potentially cause to specimen to behave more brittle. For Approach B, it can be noticed that method B1 generally have lower flow values than those of B2 and B3. This may imply that adding WPB to hot bitumen provides more uniform blending and therefore the specimens show less deformation (i.e. flow value) at their maximum compressive capacity.

According to Thailand's Department of Highways specifications, the range for flow values is needed to be within the range of 2 to 4 mm. Therefore, for Approach A, the maximum WPB contents are 13.5%, 12.0%, and 21.9% for method A1, A2, and A3, respectively. The work from El-Saikaly also agreed with the observed findings of Approach A where the flow values of the asphaltic samples for 6-18% of WPB were in the regulated flow value range of 2.97-4.04 mm. For Approach B, WPB could replace bitumen up to 25.0%, 12.0% and 6.0% by wt. of bitumen for method B1, B2, and B3, respectively.

3) Stability value represents the compressive strength the specimens. In general, test specimen with lower air void tends to have higher stability value. In order to ensure that the strength of the constructed pavement could fulfill the specified requirements, the obtained stability values were adjusted to 95% one-sided lower confidence limit (LCL) values. Student's t-distribution with degrees of freedom (n-1) of 2 were assumed for each test set. It should be noted that one potential factor that could affect the width of the confidence interval is the size of the sample. Figure 2 shows the relationship between the average Marshall stability (95% LCL) and WPB content. Within the study range, all the average stability values from Approach A are higher than that of the conventional method. In general, the stability values increase as the WPB content increase before reaching the optimum point of 15-20% WPB. For Approach B, WPB tends to give negative effect to stability values. The possible reason is because the amount of bitumen was reduced and replaced by WPB. For method B2 and B3, the mixing temperatures was not kept constant during the blending process. Therefore, it is possible to have partly melted plastic formed during the blending process and was left scattering in the samples. This could affect the uniformity of pavement structures and therefore their stability values.

2. Maximum Amount of WPB

The maximum WPB contents was determined based on Thailand's Department of Highways requirements in which air voids, flow and stability values of the specimens are compared against the specified values. Table 2 shows the maximum amount of WPB for each property and each mixing method that the properties of the AC samples were within the standard limits. The last column of the table shows the maximum % WPB that all three required properties were satisfied. In general, it was found that all methods are capable of producing AC that meet the requirements. For Approach A, the maximum WPB are 13.5%, 12.0%, and 21.9%, respectively. In regards of Approach B, the maximum contents of WPB tend to be lower than those from Approach A, i.e. the maximum amount are 12.2%, 3.6%, and 6.0% for method B1, B2, and B3, respectively. Table 2 shows a summary of the maximum amount of WPB, calculated from the "Pass All" column in Table 2, that can be blended to AC mixture. For convenience implementations, the unit for WPB content in this table is shown in mass (g) per square area (sq. m.) per thickness (cm) of pavement.

Table 2. Maximum WPB contents (percent by weight of bitumen) for pavement subjected to light to heavy traffic.

Mixing Concept	Mixing Method	Maximum % WPB by wt. of Bitumen				
		Air Void	Flow	*Stability	Pass All	(g/sq.m./cm)
Approach A (Adding method)	A1	18.0%	13.5%	25.0%	13.5%	169
	A2	17.5%	12.0%	25.0%	12.0%	150
	A3	22.0%	21.9%	25.0%	21.9%	274
Approach B (Replacing method)	B1	12.2%	25.0%	25.0%	12.2%	152
	B2	3.6%	12.0%	6.0%	3.6%	45
	B3	10.8%	6.0%	23.2%	6.0%	75

* Stability values at 95% one-sided lower confidence limit (LCL)

Considering bitumen costs for Methods A1, A2 and A3, where waste plastic bags are added, are similar to those of a conventional asphaltic concrete pavement, because the amount of asphalt is not reduced. The difference is that the stability values of the pavement are higher. However, if Methods B1, B2 and B3, where asphalt is reduced and replaced by waste plastic bags as recommended, it can be calculated that the bitumen cost (baht/sq.m./cm) would be reduced from 58.58 to 53.67, 57.13, 56.16 baht/sq.m./cm, respectively. This expenditure is based on the standard price of bitumen at 32,243.33 baht per ton (standard price in October 2013, Ministry of Commerce).

3. Implementation of the Process

In this section, the method A3 (Adding Approach - Mixing WPB to AC mixture) was conducted. This method was chosen because it is considered to be suitable for rural areas since it need no special cooperation from the mixing plant.

For the pilot study at Chiang Mai Rajabhat University, a total of 12 bins exclusively for waste plastic bags were installed on the campus. The quantity of waste plastic bags was recorded for six months starting from January 2013 to end of June 2013. It was found that the average quantity of waste plastic bags was 9.14 kg/day which is approximately 1.1% of all solid wastes in the community. A 1,000-meter-long road was constructed at Chiang Mai Rajabhat University (Mae-rim campus) via method A3. With a brief training, the participated local contractor and workers were able to adopt the proposed method in addition to their regular working process. Fig. 5 shows a picture of a volunteer distributing WPB over the surface of the AC mixture in which the mixing blades of the paver would then mix all the components together. While the application was seemed to be simple, strong wind and rain however raise up difficulties to the work. Shredded WPB is very light in weight and can easily be blown away by wind. Rain is also an undesired situation because it can quickly lower the surface temperature of the asphaltic mixture. The effect of rain was observed in this study where small pieces of WPB were found unmelted in the pavement. The construction was therefore halted for favorable weather condition.

The total area of the constructed road was 3,493 sq. m. with a thickness of 5 cm. The total amount of shredded WPB used was 4,775 kg. In other words, the amount of waste plastic bags that were produced in the University community for 525 days have been eliminated by using it to enhance the stability of the asphaltic pavement being used in their own community (calculated based on the recorded quantity of waste plastic bags in the main campus of 9.14 kg/day).



Figure 5. Mixing shredded WPB at construction site

Implementation of the research results was subsequently carried out in 4 provinces located in 4 different regions of Thailand. Project participants include contractors, government officials, engineers, and local people in the communities. Details of the implementations (A3 method) in each province are as follow:

1) Chiang Mai (Northern Thailand): The proposed A3 method was used to construct the main entrance road of Mae-Sa Luang Temple. The constructed road covers 280 sq.m. area. The amount of WPB used was 280 kg.

2) Samutsongkram (Central Thailand): The implementation was held in the municipal district of Samutsongkram where a total of 280 sq.m. pavement was constructed and 280 kg of WPB was used.

3) Khonkaen (Northeastern Thailand): A total of 90 kg of WPB was used to construct a 90 sq.m. recreation ground.

4) Krabi (Southern Thailand): A total of 200 kg of WPB was utilized to construct a 1200 sq.m. recreation ground in Ao Nang area.

5) The success of the implementation process has demonstrated that the proposed method is one effective way to eliminate waste plastic bags in communities. It also introduces a new approach to construct an environmentally-friendly road to communities. A well cooperation between the government and local communities will be the key factor to the success of utilizing the proposed methods in the future.



Conclusions

Based on the study results, the following conclusions can be made:

1) All of the proposed methods, WPB addition or replacement, have been shown to be capable of satisfying the requirement for heavy traffic pavement specified by Thailand's Department of Highways where the stability value is needed to be greater than 8 kN. Therefore, adoption of WPB blending method depends on each community own judgment and circumstances. Method A1, A2, B1, B2 are applicable and suitable for large-scale pavement construction, as these processes need cooperation with the manufacturing plant. Method A3 and method B3 would be appropriate for small-scale project where WPB can be blended at the construction site.

2) Within the study range for WPB content, adding WPB by Approach A shows to provide positive effect to stability values, unlike Approach B.

3) WPB can be blended to AC mixture at larger amount by Approach A than by Approach B. The maximum WPB content for Approach A is up to 274 g/sq. m./cm (method A3) while the maximum WPB content for Approach B is limited to 152 g/sq. m./cm (method B1)

4) When it is preferred to have WPB mixed at site, i.e. using method A3 or B3, wind and rain can potentially lower the mixture temperature. Distributing shredded plastics can also be difficult under gust wind scenarios.

5) The proposed methods have been shown to be alternative approaches to relieve waste plastic bags problems in communities. Due to its ability to enhance the properties of AC pavement and relieve the plastic waste problems in the communities, the implementation of the study results has been extended to four major regions of the country which includes Chiang Mai (Northern Thailand), Samut Songkram (Central Thailand), Khonkaen (Northeastern Thailand), and Krabi (Southern Thailand).



Acknowledgment

I would like to gratefully acknowledge the National Research Council of Thailand (NRCT) under the program Research Scholarships for Graduate Students 2015.

 **References**

- Ahmadinia, E., Zargar, M., Karim, M.R., Abdelaziz, M., Shafiqh, P. (2011). Using waste plastic bottles as additive for stone mastic asphalt. **Mater. Design.** 32, 4844-4849.
- Al-Hadidy, A.I., Yi-qiu, T. (2009). Effect of polyethylene on life of flexible pavements. **Constr. Build. Mater.** 23. 1456-1464.
- American Society for Testing and Materials ASTM D6927. (2004). **Marshall Stability and Flow of Bituminous Mixtures**, ASTM International.
- Barnes, D.K., Galgani, F., Thompson, R.C., Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. **Phil. Trans R. Soc. B.** 364, 1985-1998.
- Department of Highways Thailand. (1999). **Asphalt Concrete or Hot-Mix Asphalt. Standard No. DH-S 408/2532.** Bureau of Materials. Analysis and Inspection.
- El-Saikaly, M.A. (2013). **Study of the Possibility to Reuse Waste Plastic Bags as a Modifier for Asphalt Mixtures Properties (Binder Course Layer).** The Islamic University of Gaza.
- Khan, A., and Khan, R. (2010). **Plastics recycling is out in the Streets.** Tehelka Magazine. New Delhi. Vol 7. Issue 39, 110.
- Verma, S.S. (2008). Roads from Plastic Waste. Point of view. **Indian Concrete Journal**, 43-44.