ผลของเศษยางพาราบดผสมในมวลรวม ที่มีผลต่อคุณสมบัติความต้านทานการยุบตัวของแอสฟัลต์คอนกรีตผสมร้อน

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Influence of Crumbed Para Rubber Modifier in Aggregate Blend on Deformation Resistance Properties of Hot Mix Asphalt

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หัทธพล สิลิมะโนธัม : ผลของเศษยางพาราบดผสมในมวลรวม ที่มีผลต่อคุณสมบัติความต้านทานการยุบตัวของแอสฟัลต์คอนกรีตผสมร้อน (Influence of Crumbed Para Rubber Modifier in Aggregate Blend on Deformation Resistance Properties of Hot Mix Asphalt) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร.บุญชัย แสงเพชรงาม, 57 หน้า.

งานวิจัยนี้นำเสนอแนวทางในการเพิ่มเศษยางพาราบดระหว่างขั้นตอนการผลิตส่วนผสมแอสฟัลต์คอนกรีตด้วยกระบวนการผสมแบบแห้ง ซึ่งมีจุดเด่นกว่ากระบวนการผสมเปียกด้านความสะดวกในการตรวจสอบคุณภาพส่วนผสม และมีการปรับปรุงกระบวนการผลิตส่วนผสมในโรงงานเล็กน้อย โดยมุ่งเน้นศึกษาคุณสมบัติเชิงวิศวกรรมของส่วนผสมแอสฟัลต์คอนกรีตที่เกี่ยวข้องกับการต้านทานการเสียรูปถาวรจากการผสมเศษยางพาราบดด้วยรูปแบบที่แตกต่างกัน การทดสอบเริ่มจากการออกแบบส่วนผสมแอสฟัลต์คอนกรีตตามวิธีมาร์แชลล์ ซึ่งส่วนผสมพื้นฐานประกอบด้วยมวลรวมชนิดหินปูนและแอสฟัลต์เกรด Pen 60/70 ในปริมาณ 5.4% โดยน้ำหนักส่วนผสม หลังจากนั้นผสมยางพาราบดเข้ากับส่วนผสมแอสฟัลต์คอนกรีตด้วยวิธีผสมแบบกระจายตัวและวิธีแทรกชั้นยางพารา ในสัดส่วน 2% โดยปริมาตรมวลรวม ส่วนผสมจากแต่ละรูปแบบถูกบดอัดเป็นทรงกระบอกตามข้อกำหนดการทดสอบด้วยเครื่องบดอัดแบบไจราทอรี่ แล้วนำไปทดสอบคุณสมบัติต่าง ๆ ที่เกี่ยวข้อง คือ กำลังรับดึงทางอ้อม ตามมาตรฐาน ASTM D 6931-12 โมดูลัสยืดหยุ่น ตามมาตรฐาน ASTM D 4123-82 และการต้านทานการไหล ตามมาตรฐาน AS 2891.12.1_1995 ผลการทดสอบแสดงให้เห็นว่าการเติมเศษยางพาราบดผสมเข้ากับส่วนผสมแอสฟัลต์คอนกรีต สามารถเพิ่มประสิทธิภาพด้านวิศวกรรมของแอสฟัลต์คอนกรีตทุกด้าน โดยเฉพาะอย่างยิ่งสมรรถนะการต้านทานการไหลซึ่งเกี่ยวเนื่องกับอายุการใช้งานของผิวทาง โดยการเติมยางพาราบดแบบกระจายตัวมีประสิทธิภาพมากที่สุด และมีความซับซ้อนต่ำในกระบวนการผลิตส่วนผสมและการก่อสร้างสายทาง โดยมีการใช้ปริมาณยางพาราในส่วนผสมมากกว่าวิธีอื่น ๆ และมีประสิทธิภาพการต้านทานการไหลที่ดีกว่าส่วนผสมรูปแบบปกติ 3 เท่า

ภาควิชา	วิศวกรรมโยธา	ลายมือชื่อนิสิต	....
สาขาวิชา	วิศวกรรมโยธา	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
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HATTHAPHONE SILIMANOTHAM: Influence of Crumbed Para Rubber Modifier in Aggregate Blend on Deformation Resistance Properties of Hot Mix Asphalt. ADVISOR: ASST. PROF. BOONCHAI SANGPETNGAM, Ph.D., 57 pp.

This research presents the influence of crumbed para rubber which is added into a portion of aggregate in hot mix asphalt (HMA) during the batch mixing process or called "Dry Process". The dry process has an advantage on its simplicity of quality inspection and less modification in the hot mix plant production process. This study has investigated the effects of adding crumbed para rubber particles on the engineering properties related to permanent deformation resistance of asphalt concrete. In this study, the asphalt mixture is prepared via Marshall Mix design, which contained with limestone and asphalt cement of Pen 60/70 at 5.4% by total weight. Crumbed para rubber at 2% by total volume was added in asphalt mixture via two methods, dispersive mixing method and layer method. The specimens that prepared from each method were compacted to cylinder shape according to the requirement of testing standard using Gyratory compactor. The specimens were tested to find the indirect tensile strength values according to ASTM D 6931-12, resilient modulus values according to ASTM D 4123-82 and dynamic creep test according to AS 2891.12.1_1995. The results showed that adding crumbed para rubber in aggregate increasing the engineering properties of asphalt concrete such as the strength, the elastic recovery, the deformation resistance and the longer service life. The dispersive mixing method is the most effective method and introduces many advantages than other methods such as less complexity in mixture production and road construction, in the other hand, this method contains more content of para rubber to modification than "Wet-Para modified AC." From the results, Mixtures from dispersive mixing method shows a better performance in deformation resistance for 3 times than conventional mixture

Department:	Civil Engineering	Student's Signature	....
Field of Study:	Civil Engineering	Advisor's Signature	....
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CHAPTER I

INTRODUCTION

1.1 Background

Para Rubber is the production from agriculture. In 2006, Thailand produced 3,569,033 tons, the government exported to other countries around 90 percent by total para rubber production and the local consumption of para rubber had around 10 percent. The amount of para rubber production increases every year (Rubber-Research-Institute-Department-of-Agriculture, 2014). In 2012, the domestic demand for asphalt product of Thailand had around 900,000 tons, but the supply had only 896,000 tons and the demand of asphalt product using in highway construction increases every year (Reuters, 2015). Thai government stimulates local consumption of para rubber by introducing para rubber latex into asphalt cement production for pavement construction projects throughout its national highways. In facts, the results from research works in laboratory and pilot paving sites showed that para rubber modified asphalt performed better than the ordinary asphalt. Para rubber improve the stability of the road surface, longer period to maintenance, reduce the life cycle cost (Tuntiworawit et al., 2005).Natural Rubber Modified Asphalt (NRMA) is adding a little natural rubber to mix with aggregate in hot mix asphalt concrete.. Technically, para rubber can be blended into HMA by two different ways, "wet process" and "dry process". Both methods have different strengths and weaknesses, but both have the same objective, which is to improve the mechanical properties of hot mix asphalt concrete. In the wet process, para rubber latex is mixed into asphalt cement at high temperature, named natural rubber modified asphalt (NRMA). NRMA contains para rubber content at 5% – 12% by weight of asphalt cement. The wet process, natural rubber is mixed in asphalt cement using additional process and equipment. Therefore, this process is more complex in the production of asphalt concrete. The dry process is more convenient to implement in the industry scale. The production of asphalt concrete can be proceeded with the same original equipment.

Recently, only the wet process is widely used in producing NRMA for road construction in Thailand. However, NRMA has many problems in the practitioners' view such as:

- For transporting NRMA to a hot mix plant which needs a special tanker truck with heating and agitating devices to keep para rubber consistently blended throughout the asphalt binder;
- NRMA can be aged quickly at temperature close to 200°C;
- There is no effective method to verify the amount of para rubber content in NRMA of which could control the price of NRMA.

In the dry process, para rubber in a form of crumbed particles is added into the HMA during the aggregate-asphalt hot mixing process. The dry process yields better advantages such as:

- Quantity of crumbed para rubber in asphalt concrete can be measured and monitored during construction;

- Special transportation is unnecessary ;
- It can be implemented to any HMA plant with little modification to the production process;
- Higher content of para rubber can be added to HMA comparing to the wet process (Unsiwilai.S, 2013).

Since, para rubber reacts to asphalt cement at high temperature for only few hours, para rubber is not fully melted and fused into asphalt cement body(Vichitcholchai *et al.*, 2006). This method often considers less efficient of using modifier than the wet process. However, past research works (Unsiwilai.S, 2013) indicated that the dry process allowed higher rubber content than the wet process and could result in a similar output of modification.

Crumbed para rubber is prepared by cutting para rubber in solid form into small particles. The crumbed para rubber can be added into HMA by two methods: dispersive and layer methods. This research focuses on NRMA dry process using crumbed para rubber and the resilient modulus and the deformation resistance in laboratory of asphalt concrete with crumbed para rubber.

1.2 Objectives of Study

1. To study the influences of adding crumbed para rubber with the dry process as a modifier in the hot mix asphalt on resilient modulus and resistance to permanent deformation of hot mix asphalt.
2. To study the influences of adding crumbed para rubber method on the performance of the hot mix asphalt.

1.3 Scope of Study

This research is conducted under the scope as follows:

1. The gradation of aggregate is dense grade.
2. The aggregate is limestone.
3. The crumbed natural rubber is comprised of para rubber particles with the size passing sieve no. 4 and retained on sieve no 8.
4. The asphalt cement is Pen 60/70 grade.
5. The method of mix design is Marshall Mix design.
6. The main testing is stability test, flow test, resilient modulus test and dynamic creep test.

1.4 Overall Research Methodology

The procedure in this research starts from the literature to review related to research works, such as production process of hot mix asphalt concrete which is to improve the properties of natural rubber latex and crumb rubber. The effect factors with properties of hot mix asphalt concrete are the size and quantity of grinding natural rubber in the mixture. The hot mix design and properties of specimens such as strength, elasticity, resistance to permanent deformation of asphalt concrete. Then the experimental design is conducted to cover the cases of related parameters. The specimens are then prepared according to the experstudy and compact to the sample form with the selected standard test specific. After that, the testing on resistance to permanent deformation of asphalt concrete is conducted. The test results are then analyzed to discover any meanings. This procedure is shown in figure 1.1.

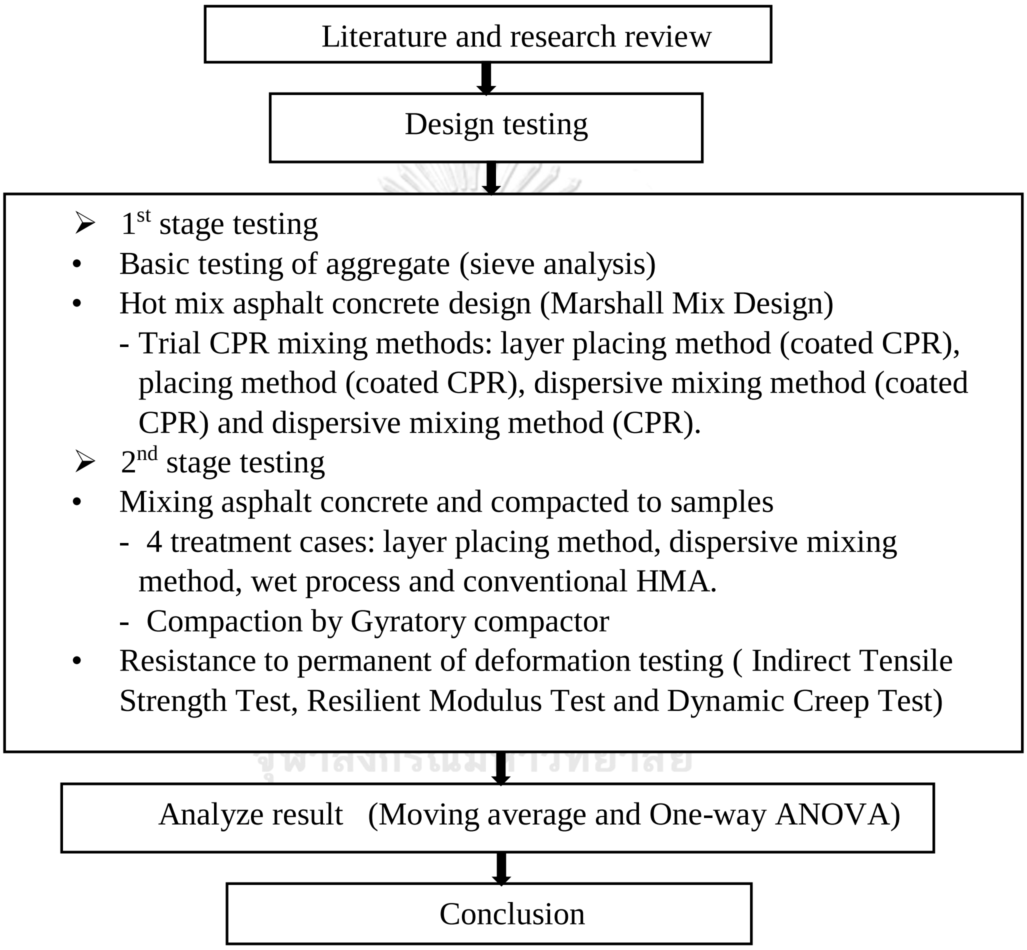

Figure 1. 1 The phase proceed the research

CHAPTER II

LITERATURE REVIEW

Recently, improving the quality of asphalt concrete with natural rubber is a method development the properties of material. Due to the improved quality of asphalt concrete, it has good several properties such as increasing the stiffness at the high operating, increasing the material elasticity at moderate operating temperature, reducing the fatigue cracking and stiffness changing at the low operating temperature and the lower thermal cracking problem.

2.1 The Technology to Improve Asphalt Concrete Material with Wet Process and Dry Process

The development of natural rubber for a long period since 1950's causes the model development for improving the quality of asphalt concrete with natural rubber. The procedure can divide into 2 main methods, such as wet process and dry process. In wet process, there are two technologies: the McDonald(batch) technology and the continuous blending technology. The dry process has three technologies: the PlusRide technology, generic dry technology, and chunk rubber technology.

- Wet process: Crumb Rubber Modifier (CRM) in the wet process is blended with asphalt cement before the CRM mixed in aggregate to modified binder. There are two technologies such as:
  - ☞ The McDonald technology: Before introduction into the mix, the CRM must be mixed in a blending tank and reacted in a holding tank. The Hot Mix Asphalt (HMA) mixture had some point difference between the production of McDonald HMA and the conventional HMA, which is the pre-blending, and reaction of the CRM with asphalt cement to produce an asphalt rubber binder. The temperature of asphalt cement should be 176 to 205 degree Celsius for adding the CRM in asphalt cement with the quantity of CRM around 15 to 22 percent by asphalt weight and the CRM range sieve No.10 to 30. The reaction time between CRM and HMA should be at least 45 minutes.
  - ☞ The continuous blending technology: The continuous blending technology has the procedure method similar to the McDonald technology, but there are some point different such as the size of CRM is sieve No.80 that is smaller than CRM's McDonald and the quantity of CRM is 5 to 20 percent by asphalt weight.
- Dry process: Crumb rubber is a material to replace aggregate before adding the asphalt cement to the blended mixture. The dry process is similar the construction site in general HMA and easily in during mixture. There are two technologies such as:

- The PlusRide technology: This technology primarily processes to incorporate CRM into a gap-aggregate before mixing asphalt cement and producing a rubber modified hot mix asphalt concrete (RUMAC). In general, a mix design using the concept includes the aggregate size as crumb rubber passing No.20 sieve to modified binder.
- The generic dry technology: In 1986, Takallou created the new technology to add crumb rubber in HMA, named generic dry technology. This technology focus in CRM to incorporate into the conventional dense graded HMA mixed with the dry process. Generally, a conventional dense grade HMA using a lower amount of CMR and size No.80 sieve to modified binder.
- The chunk rubber technology: This technology was popular in the cold region, focused on increasing the maximum aggregate size and increased the quantity of crumb rubber. Furthermore, this technology was developed or improved from the PlusRide technology (Heitzman, 1992).

2.2 Improved Asphalt Concrete Material with Natural Rubber Review

In 1949, Netherland was the first country in the world to conduct an experiment natural rubber in asphalt cement to construct the surface road. The result showed the long life service road reduced the dust on the road and reduced maintenance cost. Therefore, the other country tried to use natural rubber in the surface road such as in Virginia, Ohio, Minnesota, and Texas, which had a good result as the surface road not change with temperature and was resistance to erosion of rain.

In Asia, Malaysia was the first country to conduct an experiment natural rubber in asphalt concrete in 1951. In 1978-1988, Rubber Research Institute of Malaysia (RRIM) used natural rubber 5% of total asphalt cement with three roads as Sungaikolok road with 3 kilometers distance, the road to Kuala Lumpur airport with 50 kilometers distance and road in the Putrajaya city with 15 kilometers distance.

In India, Rubber Research Institute of India and Ministry of Road Transport and Highways, the government of India joined to use natural rubber latex with 2% of total asphalt cement weight in the construction road. In 1974, the road between Trivandrum and Kollam city constructed by natural rubber latex mixed in asphalt concrete and had the distance 1 kilometer. The result shown that the period maintenance road constructed by natural rubber latex in the surface road be a long period than the road without mixing natural rubber latex around three times of period maintenance time (Kritsada *et al.*, n,d,).

In Thailand, there are many types of research to develop natural rubber using in the road construction. In general, every country wants to comfort the transportation, so the government must develop road to solve many problems. The main choice is to use natural rubber in the industry or consumed more rubber that is natural because natural rubber is a big problem in Thailand and modified surface road with natural rubber. The research of (Tuntiworawit *et al.*, 2005) studied the engineering properties of asphalt cement and asphalt concrete mixtures with natural rubber in the format-wet process for improving the stability and flow of asphalt pavement and bringing a long service life expectancy. The experiment of research had AC60/70; the aggregate size was nominal size at 12.5 millimeters and had the variable quantity natural rubber latex with 1,3,5,7,9,11 and 13 percent by total weight. The mixture between asphalt cement and natural rubber latex started from heating bitumen in a hot plate at a temperature about 140-150 degree Celsius and stirred by the high shear mechanical mixer in 5000 rpm speed with during time 20-30 minutes. This research determined the optimum binder content at 4 percent air void by Marshall Method and compacted by Gyratory Compactor to control air void at 7 percent. The basic test of this research had penetration test, softening point test, penetration index test (PI), ductility test, torsional recovery test, toughness and tenacity test and Brookfield viscosity test. Furthermore, this research tested the engineering properties such as indirect tensile strength test (IDT) with AASHTO T283, resilient modulus test (MR) with AASHTO TP31, fatigue life test and dynamic creep test with AS 2891.12. This result showed that the optimal proportion natural rubber latex mixture in asphalt cement was 9 percent, the asphalt mixture with natural rubber increased the quality of asphalt cement then non-natural rubber mixture and reduced maintenance cost for road pavement in a long term.

The finding of (Vichitcholchai et al., 2006) studied about the appropriate ratio of asphalt cement and natural rubber by adding Ribbed Smoked Sheet (RSS). The parameter of RSS changing had 0, 2,4,6,8 and 10 percent by total asphalt weight. The preparation of asphalt cement was heating RSS at 70 degree Celsius within 30 minutes, then added RSS in asphalt cement at 150-170 degree Celsius and used a high shear mixer to mix asphalt cement within 2 hours. Finally, the procedure took in the oven at 120 degree Celsius in 24 hours. This research had the properties of asphalt mixed RSS such as penetration, softening point penetration index, torsional recovery, toughness-tenacity and viscosity test. The result showed that 6 percent RSS of total asphalt weight was the most effective to improve the properties of asphalt cement.

The research of (Kobchai *et al.*, 2014) studied about the result of the hot mix asphalt concrete mechanical properties research with the wet process. This research used AC 60/70, had 5 parameters such as 3,4,5,6 and 7 percent of total asphalt weight and the maximum of aggregate sieve No 3/4” or 19 mm. This research preceded to compaction with Marshall Method and prepared the material such as cutting the natural rubber in a small size, then adding in asphalt cement at 200 degree Celsius with during time 6-9 hours and often to stir the asphalt cement. The standard test for this research had two main tests: the first test is stability and flow. This test boiled the water at 60 degree Celsius and put the samples in the bath with during time 30 minutes, then proceeding to test by Marshall Tester Machine for test stability. The second test is strength index test. This test divided into two group samples. The first samples group put in vacuum pot in 1 hour and then put in salt solution by salt quantity 5g per liter at the temperature 60 degree Celsius within 24 hour. The second sample group put in the bath at temperature 25 degree Celsius within 1 hour. The result shown the optimal quantity of Para rubber to modify asphalt cement is 3 percent of total asphalt cement.

The research of (Punnawat *et al.*, 2014) studied the engineering properties and comparison between crumb rubber and natural rubber latex. The equipment of this research had asphalt cement AC 60/70, fixed quantity of crumb rubber and latex rubber by 5 percent of total asphalt cement, the maximum aggregate size is 12.5 mm (1/2 inch), crumb rubber size is sieve passing No 8, and the characteristic of mold be a rectangle (75*75*150 mm). The next proceeding compact the sample with five layers in rectangle mold at 140 degree Celsius and had 30 mm per each layer. Then, the procedure tested samples with displacement-controlled compression loading (50 KN or 5ton), load-controlled compression, and extension loading machine. This research tested penetration, ductility, softening point, Marshall and cyclic test. The result shown that asphalt mixed with 5% latex rubber is a higher value than other model mixtures such as compressive strength, stability, and flow, stress and strain.

The research of (Prawit *et al.*, 2015) studied the properties of asphalt natural rubber latex (NRL) and the probability using NRL in commercial. This research had only bitumen standard test such as penetration test, ductility test, flash point test, viscosity test and softening point test for comparison the properties and bitumen reaction between bitumen mix natural rubber and pure bitumen. The result showed that the bitumen mix natural rubber increased the properties of bitumen and can be developed in the commercial.

The research of (Cheriet *et al.*, 2015) studied about the possibility to improve the bituminous binder by adding natural crumb rubber. The equipment of this research had AC 35/50, three aggregate proportions 38% of sand 0/3 inch size, 30% of granular size 3/8 inch and 32% of granular size 8/15 inch. The procedure added natural crumb rubber in asphalt cement at temperature 190-200 degree Celsius and mixed the asphalt with a mechanical stirrer at the speed 600 rpm within 2 hours by changing the quantity of natural crumb rubber 0,2,4,5,6 and 8 percent of total aggregate and compacted by Marshall compactor with 50 blows. This research tested Marshall and static creep test. The result showed that the most powerful was the samples adding 8% natural crumb rubber in asphalt cement.

2.3 Asphalt Mixture Performance Testing

This research had primarily test and engineering properties test. The primarily test was a basic test which is to find the basic properties hot mix asphalt concrete and to find the optimal format mixture between natural rubber and asphalt cement by the dry process. The engineering properties test was the main test to find the properties in nearly behavior traffic on the road and the quality of asphalt concrete after mixed crumb natural rubber.

2.3.1 Marshall Test

Marshall Test had three components test such as bulk density determination, stability and flow test, and density and voids analysis. Those entire tests compacted by Marshall Compactor with three different levels of blows 35, 50 and 75 times. The compaction of specimen had many steps as:

- Aggregate 1200 g
- Diameter of specimen 100 mm and height 63.5 ± 1.3 mm
- Took aggregate in the oven at a temperature 160 degree Celsius during time 4 hours
- Took aggregate in the oven at a temperature 135 degree Celsius during time 2 hours
- Reheated aggregate at a temperature 175-190 degree Celsius
- Reheated asphalt cement at a temperature 121-138 degree Celsius
- The temperature of mix at 154-160 degree Celsius
- The temperature of compaction at 138-149 degree Celsius

- **Bulk density of the compacted specimen**

After compacted, the procedure tested the bulk density of samples following AASHTO T166: Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens (Pavement-Interactive, 2017a). Before determine density, it must be coat specimen with paraffin. The formula calculates the bulk specific gravity (G_{mb}) of the specimen is given by:

- Bulk specific gravity = $G_{mb} = \frac{A}{B-C}$
- Water absorption (in percent)=$\left(\frac{B-A}{B-C}\right) \times 100$

Where:

A: mass of sample in air (g)
B: mass of SSD sample in air (g)
C: mass of sample in water (g)

- **Stability test**

The procedure tests the stability test following the standard test ASTM D 1559 (2004) be the specimen immersed in a bath of water at the temperature at 60 degree Celsius within 30 minutes. Then, the starting tested with Marshall Stability testing machine and loaded the sample until failure with a constant loading 50.8 mm per minute. The total maximum value in KN is Marshall Stability value. The flow value has measured the direction of loading in diameter changing between during time start loading and maximum loading.

- **Density and voids analysis**

Theoretical maximum density (TMD) is the ratio between mass given the volume of void less (Va=0) HMA at the temperature 25 degree Celsius and it is also called rice specific gravity. This test follows ASTM D 2041: Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures (Pavement-Interactive, 2017b). There are two methods to calculate the density of bituminous such as:

- ➢ Weighing in water method

$$G_{\mathrm{mm}} = \frac{A}{A - C}$$

Where:

A= sample mass in air (g)
C= mass of water displaced by the sample (g)

- ➢ Weighing in air method

$$G_{\mathrm{mm}} = \frac{A}{(A + D - C)}$$

Where:

A= sample mass in air (g)
D= mass of flask filled with water (g)
E= mass of flask and sample field with water (g)

Air voids is a total volume air between the coated aggregate particles a compacted paving mixture as a percent of the bulk volume. A number of air voids in a mixture is very important and had the effect to the stability and durability in HMA.

$$\text{Air voids (percent)} = \left(\frac{G_{\mathrm{mm}} - G_{mb}}{G_{\mathrm{mm}}}\right) \times 100$$

Where:

G_{mm}= Maximum specific gravity (g)
G_{mb}= Bulk specific gravity (g)

2.3.2 Indirect Tensile Strength Test

Indirect Tensile Strength Test was used to determine the tensile properties of asphalt concrete that can be further connected to the cracking properties of asphalt pavement. Furthermore, the tensile strength ratio of bituminous mixtures was an indicator of their resistance to moisture susceptibility and a measure of water sensitivity. The procedure Indirect Tensile Strength Test is accorded with ASTM D 6931-12: Standard Test Method for Indirect Tensile Strength of Bituminous Mixtures (ASTM, 2012). The characteristic test was the vertical forces with both directions as lower and upper pressure. This test preceded the rate of loading 50 mm/min at the temperature test 25°C with 80 kPa (12psi) for 100 mm specimen's diameter and 50 mm of height. Furthermore, this test was the primarily test and necessary test before the procedure tested indirect tension test for resilient modulus of bituminous mixture.

2.3.3 Indirect Tension Test for Resilient Modulus

This research proceeds the engineering properties of the permanent test following ASTM D4123-82: Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures (ASTM, 1995). This test determines the resilient modulus values for apply compressive loads with suitable waveform by measure the horizontal deformation of the specimen and assumed Poisson's ratio to calculate a resilient modulus. Furthermore, the resilient Poisson's ratio measured the recoverable vertical and horizontal deformation to calculate. The procedure of test effect includes the temperature, loads, loading frequencies and loading durations. This test had some details testing such three level temperatures 5, 25, 40 degree Celsius, three levels loading frequencies 0.33, 0.5, 1.0 Hz and loading 2 times per specimen with rotate 90 degree Celsius. In addition, the resilient modulus values were calculated by measuring the both recoverable and the continuing time to recoverable deformation between unloading and rest period portion of one cycle.

The characteristic of the specimen was cylindrical and compacted with gyratory compactor for control air void and density. This specimen cylinder had two sizes depend on maximum aggregate sizes such as the maximum aggregate size 1 inches (25mm) should have 2 inches (51mm) of height and 4 inches (102 mm) of diameter, and the maximum aggregate size up to 1.5 inches (38 mm) should have 6 inches (152 mm) and at least 3 inches (76 mm) of height. The calculation resilient modulus of elasticity shown that the behavior deformation of the specimen during loading and had the formula as:

$$E_{RI} = P(\vartheta_{RI} + 0.27)/t\Delta H_I$$
$$E_{RT} = P(\vartheta_{RT} + 0.27)/t\Delta H_T$$
$$\vartheta_{RI} = 3.59\Delta H_I/\Delta V_I - 0.27$$
$$\vartheta_{RT} = 3.59\Delta H_T/\Delta V_T - 0.27$$

Where,

E_{RI} = instantaneous resilient modulus of elasticity, psi or MPa
E_{RT} = total resilient modulus of elasticity of elasticity, psi or MPa
ϑ_{RI} = instantaneous resilient Poisson' ratio
ϑ_{RT} = total resilient Poisson' ratio
P = repeated load, lb or N
t = thickness of the specimen, in or mm
ΔH_I = instantaneous recoverable horizontal deformation, inch or mm
ΔV_I = instantaneous recoverable vertical deformation, inch or mm
ΔH_T = total recoverable horizontal deformation, inch or mm
ΔV_T = total recoverable vertical deformation, inch or mm

2.3.4 Dynamic Creep Test

This research proceeds the engineering properties of permanent test following AS 2891.12.1-1995: Methods of sampling and testing asphalt Method 12.1: Determination of the permanent compressive strain characteristics of asphalt-Dynamic creep test (Australian, 1995). This test is a permanent deformation test of asphalt concrete for comparing with the traffic on road. The characteristic of the specimen in this test had a cylindrical and compacted by gyratory compactor to control percent air voids nearly value on the road. The dimension of specimen depended on the maximum aggregate size such as specimen size 100 mm of diameter and 50 mm in height, and specimen size 150 mm of diameter and 75 mm in height.

Furthermore, this test had some conditions to preparation the specimen before testing such as:

- Percent air voids (AV) should have 5 ± 0.5%
- Test temperature (T) should have 50 ± 0.5º C
- Compressive stress should have 200 ± 5 kpa
- Loading period t_1 should have 0.5 ± 0.05 s
- Pulse repetition period t_p should have 2.0 ± 0.05 s.
- The number of cycles accumulated the strains at least 10 000 micro -strains.

The calculation of this test had the calculation of peak load and the accumulated strain to see the relationship between a number of cycles and number of strains below:

- The peak load (F)

$$F=1.571\times D^2\times 10^{-4}$$

Where,

F = the peak load to be applied in kilonewtons
D = the mean diameter of the specimen in millimeters

- The accumulated strain (ε_p)

$$\varepsilon_p = \frac{\Delta_h}{h_0}$$

Where,

Δ_h = the total axial deformation occurring in the specimen since the first load application in millimeters.

h_0 = the original height of the specimen in millimeters

CHAPTER III
METHODOLOGY

This research is divided into 4 steps for clarity and ease of operation and has the details below:

3.1 Limit Problem and Design for Testing

This research aims to study the effect of the size and the quantity of crumb natural rubber mixture in improving asphalt concrete with the dry process. This research focuses on many variables such as:

- **Strength:** indicates with modulus value as indirect tensile and resilient modulus in indirect tensile mode. This research uses the resilient modulus value because this value reflects the strength in pavement structure. The equipment for testing resilient modulus in indirect tensile mode is Universal Testing Machine (UTM) and the testing procedure is in accordance to ASTM D4123-82: Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures. The results of modulus test are the modulus values at three temperature levels. The results can be used to generate Master Curve for asphalt concrete material that forms with the combination of Time-Temperature Superposition (ASTM, 1995).
- **The ability of resistance to permanent deformation:** there are a variety of tests. For this research, dynamic creep test with Universal Testing Machine (UTM) by Australian Standard AS 2891.12.1-1995: Methods of sampling and testing asphalt Method 12.1: Determination of the permanent compressive strain characteristics of asphalt-Dynamic creep test is selected because the result of flow number is the direct indicator of the performance of asphalt concrete (Australian, 1995).

The related parameters are aggregate size, the crumb of natural rubber size, the quantity of crumb natural rubber and mixture model. Each parameter has the details below:

☞ **Gradation:** this research assigned dense grade to require for a mixture wearing coarse base on standard asphalt concrete of highway (Knowledge-Management-Department-of-Highway, 1989).

☞ **The size of crumbed natural rubber:** this research assigned crumb natural rubber to replace the same limestone aggregate size. That sieve Crumb natural rubber passing a sieve number 4 and crumb natural rubber retained a sieved number 8.

☞ **The quantity of crumbed natural rubber:** this research assigned crumb natural rubber to replace in aggregate with 2% volume of total aggregate mass. The main idea of this research adds crumb natural rubber in a part of aggregate by removing aggregate and replacing crumb natural rubber with the same volume of total aggregate.

☞ **Mixing method:** this research assigned 2 mixing methods:
- Adding coated crumbed natural rubber as a layer between two adjacent asphalt concrete layers during compaction. This method is referred later as layer placing method.
- Adding crumbed natural rubber during mixing. This method is referred later as dispersive mixing method.

In summary, the combination of asphalt concrete for this research are one gradation, one size of crumb natural rubber, one content of crumb natural rubber, two mixing methods and one referenced condition of hot mix asphalt concrete. Therefore, this research has three different formats of hot mix asphalt concrete.

3.2 Testing Process

This research uses all mixture design with Marshall for asphalt concrete. All of the testing methods are using the same source material from Suphunburi province and asphalt type Pen 60/70 from the company of Thai oil group. This research controls the same material because this research wants to know the result each mixing. This research divided in two phases of testing:

- **Phase 1: Pilot testing**

☞ **Preliminary testing:** to take into consideration the possibility of operating test and use to determine the levels of experimental design such as the production asphalt concrete by format and operating set. The experimental test considers the integrity of machine testing and to know the limitations of machine testing with that format testing.

☞ **Basic properties material testing:** to conduct testing on material properties in this research such as density, specific gravity. This testing considers the material appropriate standard testing such as Department of Highways in Thailand.

☞ **Determine the most suitable model to adding crumbed natural rubber:** to proceed the test with aggregate size and crumbed natural rubber size do not have the effect of distribution patterns and interest to adding the crumbed para rubber model such as:
- Dispersive mixing method meant that crumbed para rubber particles were mixed with hot mix asphalt (HMA) in a mixer during the post hot mixing process at the temperature 160 ºC in order to allow the crumbed para rubber particles dispersed thoroughly.
- Layer placing method meant that all crumbed para rubber that coated crumbed para rubber with asphalt cement by ratio 6:1 were placed between bottom and

top layers of hot mix asphalt at the temperature 160 ºC or crumbed para rubber layer was sandwiched between hot mix asphalt.

This research added crumbed para rubber to mix asphalt concrete with crumbed para rubber size passing sieve No.4, retained No.8 and 2% volume of total aggregate. For each pattern, there are three samples to compact with a 10cm diameter and a 5cm height by gyratory compactor.

In summary, the result of pilot testing shows the optimal asphalt binder content and the most appropriate patterns adding crumbed para rubber as dispersive mixing method and layer placing method. Furthermore, this research also includes additional two methods as conventional hot mix asphalt (HMA) and para rubber latex modifier (wet process) to compare the engineering properties of resistance to permanent deformation in each treatments. This research has 4 treatments and has the procedures mixing and compacting below:

- Conventional HMA: aggregate and asphalt cement were mixed together in a mixer at 160 ºC and then cured in oven at 160 ºC for 2 hours before compaction using gyratory compactor. This procedure was conducted following to ASTM D6925-15. This treatment case was considered as the base referenced case.
- NRMA + HMA (wet process): NRMA was used instead of asphalt cement in the conventional HMA preparation.
- Crumbed para rubber + HMA (dry process) by dispersive mixing method: aggregate, asphalt cement and crumbed para rubber were mixed together thoroughly, then cured and compacted by the same preparation procedure as in the conventional HMA.
- Crumbed para rubber + HMA (dry process) by layer placing method: at first, conventional HMA was prepared. During the HMA compaction process, half of HMA quantity was filled into the mold and lightly tamped for gaining a flat level. Then, all amount of crumbed para rubber particles were placed on the HMA as a layer. After that, the other half of HMA was placed on top of crumbed para rubber layer. The mold was then fully compacted using the gyratory compactor.

- **Phase 2: To study the engineering properties of resistance to permanent deformation by changing crumbed para rubber in hot mix asphalt concrete.**

This phase proceeds to test the strength and elasticity by ASTM D6931-12: Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures (ASTM, 2012) and ASTM D4123-82: Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures (ASTM, 1995). The first step compacts the samples with 10cm diameter and height 5cm by Gyratory Compactor. Then proceed to test with Indirect Tension digital compressor taster for find maximum loading. After receiving maximum value loading indirect tension, the procedure tests indirectly tension for resilient modulus with Universal Testing Machine (UTM) for understanding the relations between stress and strain. This test has some details such as used 10% maximum loading indirect tension strength, three variables of temperature 25, 37.5 and

50 degree Celsius and five specimens for each patterns test. Then, the procedure uses the value of resilient modulus for evaluating the quality of material. The result will show the ability loading for each pattern and elasticity of the material.

The next procedure is compacting the specimen with optimal asphalt binder content and interested the patterns to add crumb para rubber in hot mix asphalt concrete. Then proceed to Dynamic Creep test for analyzing the properties of resistance to permanent deformation, that change the quantity of crumbed para rubber and patterns adding crumbed para rubber in hot mix asphalt concrete. The result of this test is a number of cycles and minimum strain rates that shows the effective of resistance to permanent deformation in each patterns mixture. After test Dynamic Creep, this specimen cannot continue to another testing because this test destroyed samples.

This test follows Australian Standard AS 2891.12.1-1995: Methods of sampling and testing asphalt method 12.1: Determination of the permanent compressive strain characteristics of asphalt-Dynamic creep test and has the condition such as the temperature testing at 50 °C with compressive stress 200kpa in vertical until 20,000 cycles or the stress value up to 30,000 micro-strains, then proceeding to analyze the value of Flow Number (Australian, 1995).

The results of phase 2 will show the engineering properties of resistance to permanent deformation by changing from crumbed para rubber to replace rock aggregate in hot mix asphalt and can be analyzed the best pattern mixed with crumbed para rubber.

Table 3. 1 The test pattern and number of samples test

The testing phase	Proposal	Testing	First Parameter	Detail	Second parameter	Detail	Thirst parameter	Detail	Samples number	Testing number
Phase 1	Finding the appropriate of crumb natural rubber	Marshall	Gradation	**1** gradation: Dense grade	Crumbed para rubber size	1 model: crumb para rubber sieve retained number 8	adding crumbed para rubber model	2 model: - dispersive mixing method - layer placing method	Ø10cm, h 6.4cm $((1\times1\times2)\times3) = 6$	$6\times3 = 18$
Phase 2	Study the strength	Indirect Tensile Strength		**1** gradation: Dense grade	Adding crumbed para rubber and para latex model	3 model: - dispersive mixing method - layer placing method - wet process	Quantity of crumbed para rubber and para latex	2 model: - 2% CPR by total volume of aggregate - 5% PRL by total weight of OBC	Ø10cm, h 5cm $(((1\times3)+1)\times3) = 12$	$12\times1 = 12$
	Study the elastic recovery	Indirect Tension Test for Resilient Modulus	Gradation	**1** gradation: Dense grade	Adding crumbed para rubber and para latex model	3 model: - dispersive mixing method - layer placing method - wet process	Quantity of crumbed para rubber and para latex	2 model: - 2% CPR by total volume of aggregate - 5% PRL by total weight of OBC	Ø10cm, h 5cm $(((1\times3)+1)\times3) = 12$	$12\times1 = 12$

Table 3. 2 Continue the test pattern and number of samples test

The testing phase	Proposal	Testing	First Parameter	Detail	Second parameter	Detail	Thirst parameter	Detail	Samples number	Testing number
Phase 2	Study the engineering properties of resistance permanent deformation	Dynamic Creep Test	Gradation	**1** gradation: Dense grade	Adding crumbed para rubber and para latex model	3 model: - dispersive mixing method - layer placing method	Quantity of crumbed para rubber and para latex	2 model: - 2% CPR by total volume of aggregate - 5% PRL by total weight of OBC	Ø10cm, h 5cm (((1×3)+1)×5) = 20	20×1 = 20
Summary									Ø10cm, h 6.4cm and loose mix 18 samples	Marshall 18 times
									Ø10cm, h 5cm 12 samples	Indirect Tensile Strength Test 12 times
									Ø10cm, h 5cm 12 samples	Indirect tension test for resilient modulus 12 times
									Ø10cm, h 5cm 20 samples	Dynamic creep 20 times

Table 3. 3 The estimation time for testing

Step	Activity	Samples	Samples per day	Testing time (day)	Remark
1	Prepare samples Ø10 cm, h 6.4 cm and loose mix	18	6-10	3-5	Beginning test
2	Prepare samples Ø10cm, h 5 cm	44	3	15-25	Waiting result from step 4
Total compaction time				18-30	
3	Marshall Test	18	8-11	3-5	Testing after step 1
4	Indirect Tensile Strength Test	12	3	3-5	Testing after step 2
5	Indirect Tension Test for Resilient Modulus of Bituminous Mixtures	12	3	5-8	Testing after step 2
6	Dynamic Creep Test	20	1-3	20-25	Testing after step 2
Total testing time				31-43	-
Total procedure time				49-73	-

3.3 Analyze the Testing Result

From the result of proceeding, the test analyzes the different each pattern that will show the properties effect of resistance to permanent deformation asphalt concrete for appropriate to improve the better result in the future.

CHAPTER IV

RESULTS, ANALYSIS, AND DISCUSSION

After reviewing the test results according to the research procedure in chapter 3, the test results obtained from all testing. The details of the analysis of testing results are as follows.

4.1 The Pilot Testing

The pilot testing is the first step to proceed on this research and qualify the probability of each parameter, which could be improved the properties of hot mix asphalt.

4.1.1 The Preliminary Testing

The preliminary testing takes into consideration the possibility of operating test and use to determine the levels of experimental design such as the production asphalt concrete by format and operating set. The experimental test considers the integrity of machine testing and to know the limitations of machine testing with that format testing.

4.1.2 Basic Properties of Materials Testing

This step determines the basic properties of materials to produce asphalt concrete. The basic properties divided in 3 parts: asphalt cement properties, gradation properties and crumbed para properties. The details of basic properties are below:

- **Asphalt cement properties:** The basic properties of asphalt cement must be ascertained whether the asphalt cement is suitable for the production of asphalt concrete. Generally, this basic property was tested in each period of production by the company for control the quality of production and followed the standard test. This research used the penetration grade AC 60/70 from PPT public limited company (PTT PLC), that had the testing result on table 4.1 below:

Table 4. 1 The properties of asphalt cement from PTT PLC

Order	Testing	Standard	Testing result
1	Penetration	ASTM D-5	62 (1/10 mm)
2	Softening Point	ASTM D-36	46.4 ºC
3	Specific Gravity	ASTM D-70	1.03
4	Kinematic Viscosity at 135ºC	ASTM D-445	293.3 cSt
5	Kinematic Viscosity at 150ºC	ASTM D-445	149.8 cSt

- **Gradation properties:** The specific gravity is very important because the concept of research will use the crumbed para rubber by replacing some aggregate. This concept implements the replacement by the percent volume of total aggregate. The volume is too hard measure the quantity to replacing in hot mix asphalt, therefore the replacement of volume method changed to the weight for comfortable mixed in hot mix asphalt. The aggregate of research used limestone in hot mix asphalt, that from stone gridding mill on Kanjana Silapun Company at U Thong district, Suphan Buri province. This research divided into 3 aggregate sizes such as coarse aggregate size 3/4 inch, fine aggregate size 3/8 inch and dust. The aggregate analyze sieve analysis method (ASTM C136 Sieve Analysis of Fine and Coarse Aggregates) and shown on table 4.2 and figure 4.1. Furthermore, the specific gravity test divided 2 tests as the specific gravity of coarse aggregate (ASTM C 127: Specific Gravity and Absorption of Coarse Aggregate) and the specific gravity of fine aggregate (ASTM C 128: Specific Gravity and Absorption of Fine Aggregate) and shown on table 4.3.

Table 4. 2 The aggregate sieve analysis

Sieve	**Size, d (mm)**	**% Passing**		
		Cold Bin		
		3/4" (Bin 1)	**3/8" (Bin 2)**	**Rock Dust (Bin 3)**
1 inch	25	100.00	100.00	100.00
3/4 inch	19	100.00	100.00	100.00
1/2 inch	12.5	58.85	100.00	100.00
3/8 inch	9.5	29.37	100.00	100.00
# 4	4.75	3.37	92.88	98.88
# 8	2.36	1.05	7.37	72.10
# 16	1.18	0.90	3.14	44.33
# 30	0.6	0.84	2.70	29.98
# 50	0.3	0.78	2.45	21.61
# 100	0.15	0.67	2.17	14.76
# 200	0.075	0.14	0.44	11.33
Pan	0	-	-	-

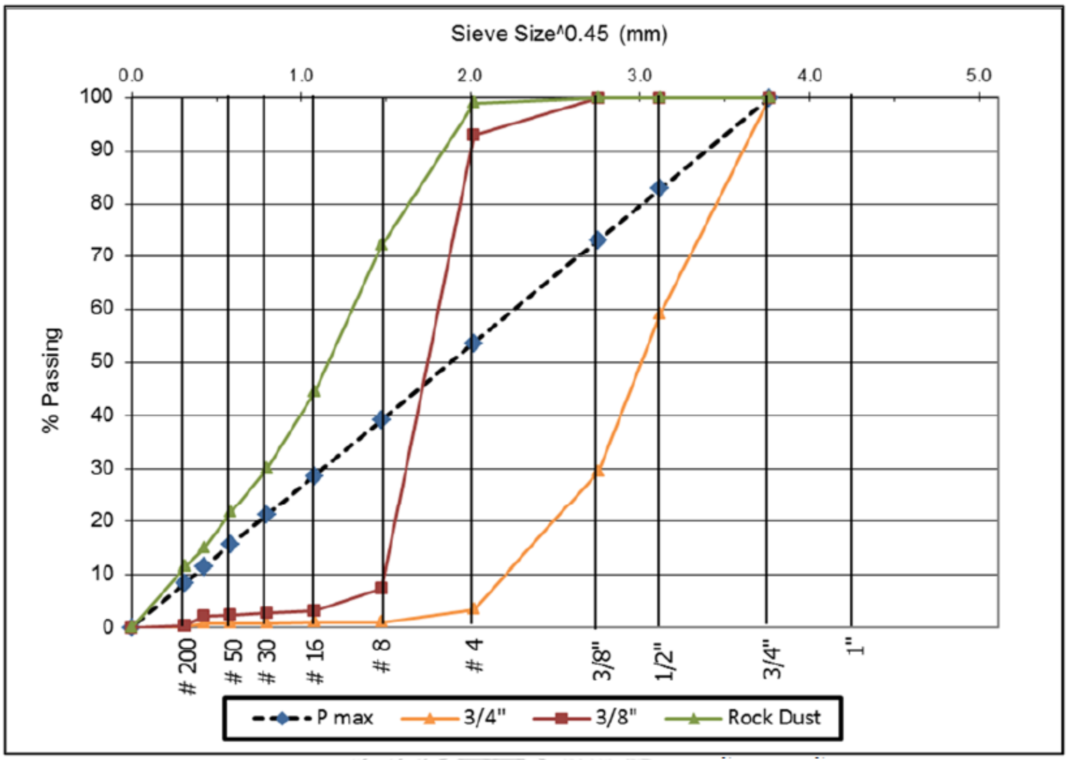

Figure 4. 1 Sieve analysis aggregate size 3/4 inch, 3/8 inch and rock dust.

Table 4. 3 The average specific gravity of aggregate

Norminal Size		**Avg. Specific Gravity (G_{sb})**	**% Water Absorption**
3/4" (Bin 1)	Coarse Aggregate	2.695	0.555
	Fine Aggregate	-	-
	Dust	-	-
3/8" (Bin 2)	Coarse Aggregate	2.701	0.560
	Fine Aggregate	-	-
	Dust	-	-
Rock Dust (Bin 3)	Coarse Aggregate	-	-
	Fine Aggregate	2.686	0.728
	Dust	2.637 (G_{sa})	-

- **Crumbed para rubber properties:** Based on research concept, it seems that the crumbed para rubber was replaced in some aggregate by volume of aggregate. Therefore, the basic properties of crumbed para rubber is very important in the asphalt mixture design as specific gravity of crumbed para rubber which was similar to specific gravity of Portland cement by ASTM C 188: Density of Hydraulic Cement. After testing, the specific gravity of crumbed para rubber is 0.9455 (G_{sb}=0.9455).

4.1.3 Asphalt Concrete Mix Design

The Asphalt Concrete Mix Design determined the gradation blended referring to dense grade with the maximum size 19 mm and represented on figure 4.2. From the figure 4.2, the gradation focused on the fines and dust aggregates. Therefore, this research focused to improve asphalt concrete with a small size crumbed para rubber and chosen the procedure test with dry process.

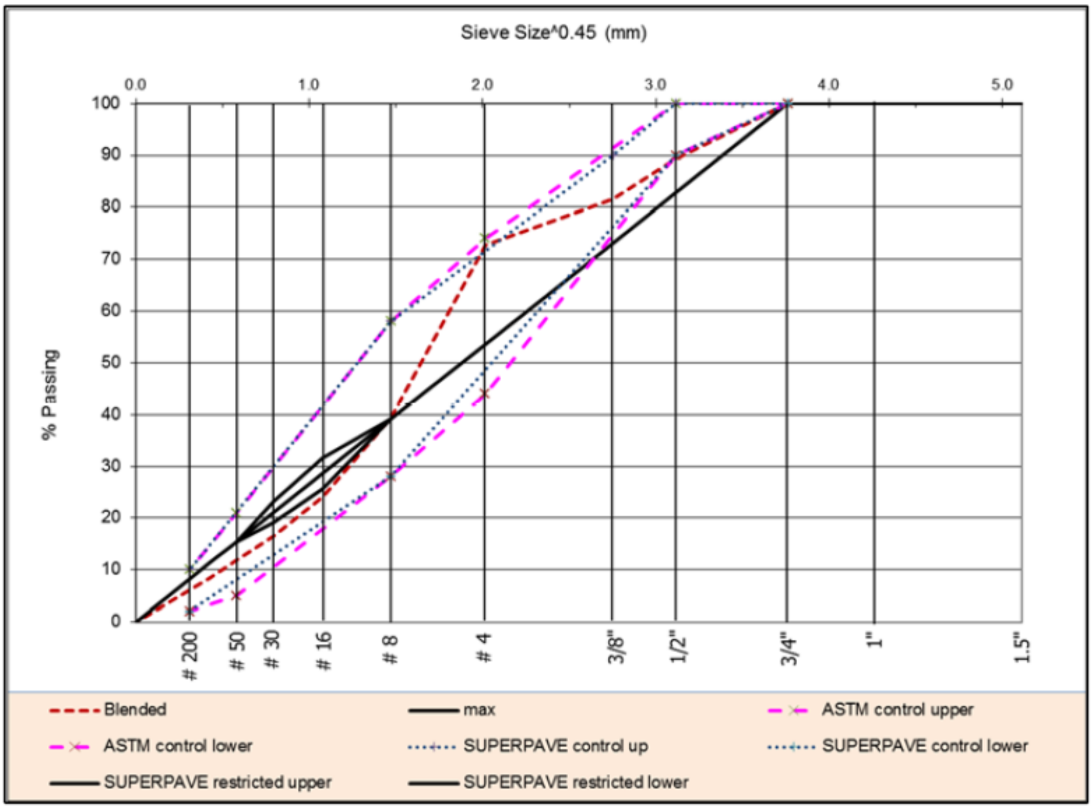

Figure 4. 2 The particle Distribution of gradation

The next step, considering the viscosity of asphalt cement grade AC 60/70 at various temperature to determine the preparation of asphalt concrete based on the asphalt cement properties on above as:

- Status mixture requires a viscosity range 0.17±0.02 Pa-s, equivalent to a viscosity of asphalt at 140 to 146 °C
- Status compaction requires a viscosity range 0.28±0.02 Pa-s, equivalent to a viscosity of asphalt at 129 to 134 °C

Form the above information, this research had the preparation to mix asphalt concrete with the limestone heat at 180 ºC for 4 hours and asphalt cement at 160 ºC for 3 hours. After that, the procedure mixed with the electric mixer for 1-2 minutes and the proportion of asphalt increased 0.5% with the range 4% to 6% by total weight. Then, the mixture was incubated by the oven at 160 ºC for 2 hours that simulated the asphalt deterioration in the transportation from the factory to the construction site (short-term aging). Next, the procedure compacted to the cylinder shape by Marshall Compactor with 75 times per side that had the equivalent high traffic (over 1,000,000 axial) by controlled the temperature at least 135 ºC and using another mixture to find the maximum density or Maximum Theoretical Density of Mixture (G_{mm}). Finally, using the specimens determined the density of specimens by the bulk specific gravity of mixture test (G_{mb}) and proceeded the Marshall Stability and Flow Test to find the optimal binder content (OBC).

Table 4. 4 The properties of gradation in asphalt mixture design

Properties	**Bin 1**	**Bin 2**	**Bin 3**	**Aggregate blend**
Material type	Limestone	Limestone	Limestone	
Nominal size	3/4”	3/8”	Dust	
Bulk specific Gravity (G_{sb})	2.695	2.701	2.678	2.687
Proportion (%)	26	22	52	100
G_{mm} @ 5.4 % Binder Content	-	-	-	2.505

Table 4. 5 The optimum binder content result

Finding the amount of asphalt				
%AC @ max Gmb		5.9%	Optimal binder content (OBC)	5.4%
%AC @ mx stability		4.9%		
%AC @ middle AV limit		5.4%		
High volume traffic requirements				
Terms	**Testing result**	**Lower**	**Upper**	**Result**
%AV @ OBC (%)	4	3	5	Passed
Stability @ OBC (KN)	10.95	8	-	Passed
Flow @ OBC (0.25mm)	13.2	8	14	Passed
VMA @ OBC (%)	15.6	14	-	Passed

From the table 4.5, the optimal binder content was 5.4% by total weight and the quantity of crumbed para rubber was 2% by total volume of aggregate based on the study crumbed rubber research (Siwarak, 2013).

4.1.4 Determine the Suitable Method for Adding Crumbed Para Rubber

This step was the trial test to find the efficiency method to add crumbed para rubber in hot mix asphalt and the procedure testing followed Marshall mix design and testing. This research created 5 patterns to added crumbed para rubber in mixing method such as:

- Layer placing method (coated crumbed para rubber with asphalt cement by ratio 6:1)
- Dispersive mixing method in cold aggregate (coated crumbed para rubber with asphalt cement by ratio 6:1)
- Dispersive mixing method in HMA (coated crumbed para rubber with asphalt cement by ratio 6:1)
- Dispersive mixing method in HMA (crumbed para rubber)
- Conventional HMA (no crumbed para rubber)

Table 4. 6 The Marshall Test result of 5 patterns mixture

Terms	**Average testing results**				
	Layer placing method	**Dispersive mixing method in cold aggregate**	**Dispersive mixing method in HMA(no coated)**	**Dispersive mixing method in HMA(coated)**	**Conventional HMA**
%AV @ OBC (%)	4.49	3.05	4.47	6.131	4.34
Stability @ OBC (KN)	10.78	10.29	10.49	9.00	10.95
Flow @ OBC (0.25mm)	13.48	13.48	13.36	13.52	13.2
Selected patterns	✓	-	✓	-	✓
Gmm @ OBC (%)	2.474	-	2.475	-	2.505
Gmb @ OBC (%)	2.349	-	2.349	-	2.380

From the table 4.6, the results that pass Marshall Standard is the layer replacing method, the dispersive mixing method and the conventional HMA. Furthermore, this research chose additional method as the para rubber latex (wet process) to produce from PTT following by the Department of Highway Standard. Finally, this research had 4 treatment cases to precede the permanent deformation test in the next step.

4.2 Indirect Tensile Strength

Indirect Tensile Strength Test used to determine the tensile properties of asphalt concrete that can be further connected to the cracking properties of asphalt pavement. Furthermore, the tensile strength ratio of bituminous mixtures was an indicator of their resistance to moisture susceptibility and a measure of water sensitivity. The procedure Indirect Tensile Strength Test is accorded with ASTM D 6931-12: Standard Test Method for Indirect Tensile Strength of Bituminous Mixtures(ASTM, 2012). The characteristic test was the vertical forces with both directions as lower and upper pressure. This profile was shown on the figure 4.3.

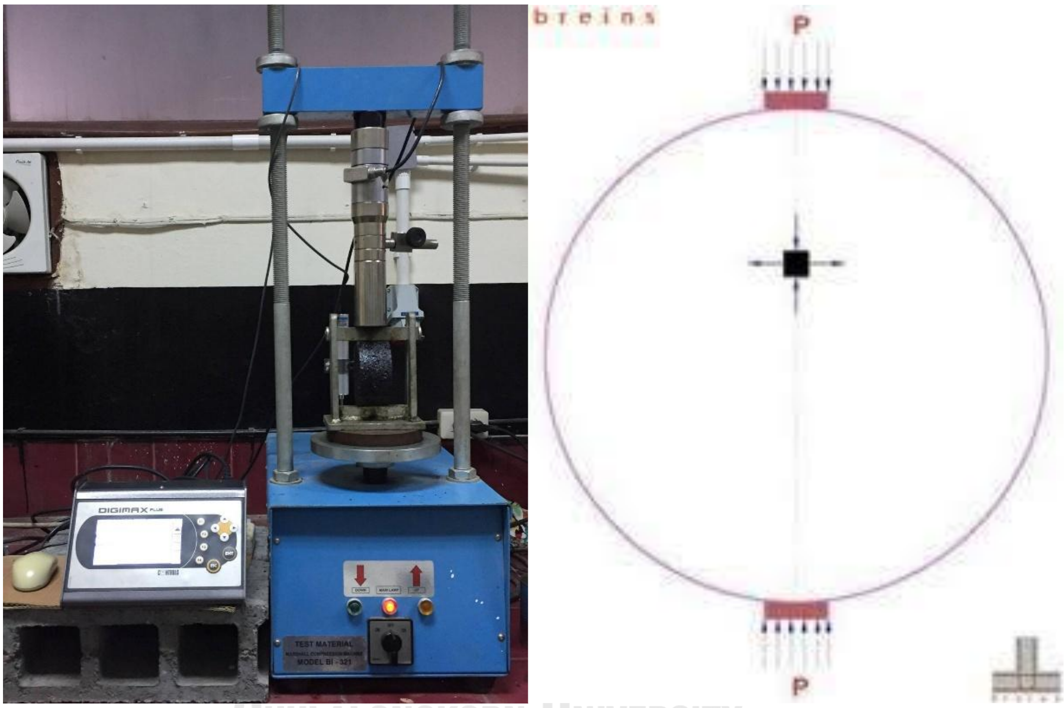

Figure 4. 3 The tensile model of Indirect Tensile Test (Online, 2017)

For this test, the specimens for all treatments were prepared by using the OBC 5.4% by total weight and compacted by gyratory compactor to control the percent air voids. After compaction finished, the specimens must be 5% air voids and the height of specimens will be 50 mm. In the conventional hot mix asphalt case, the gyratory compactor terminated the compaction when the density of specimens was 2.380 (G_{mb}) and the crumbed para rubber case, the gyratory compacted terminated the compaction when the density of specimens was 2.439 (G_{mb}). The average result of indirect tensile strength test of 4 treatments was shown in the figure 4.4.

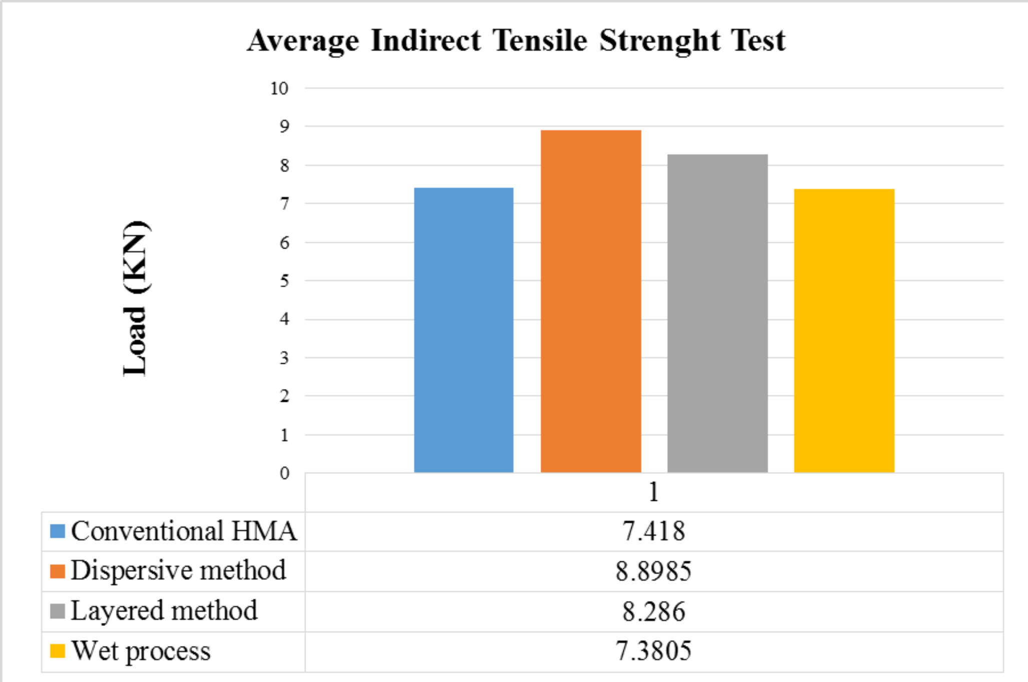

Figure 4. 4 The average result of indirect tensile strength test

Based on the result test in the figure 4.4, the highest indirect tensile strength was dispersive mixing method and higher than conventional HMA 9 %. The layer placing method was the second higher indirect tensile strength and higher than conventional HMA 5.5%. Although, the conventional HMA and the wet process were the nearly value indirect tensile strength because the wet process was the hardly method to control the same quality of each specimens.

In addition, the indirect tensile strength test was the strength test of asphalt concrete material and was the preliminary test to precede the resilient modulus test in the next procedure.

4.3 Indirect Tension Test for Resilient Modulus

Resilient Modulus value was represented the strength of asphalt concrete in specimens. If the specimens had the big resilient modulus value, it meant that this specimen had the good properties of elastic and a good strength. Furthermore, the resilient modulus value was the significance to design the road or pavement structural design.

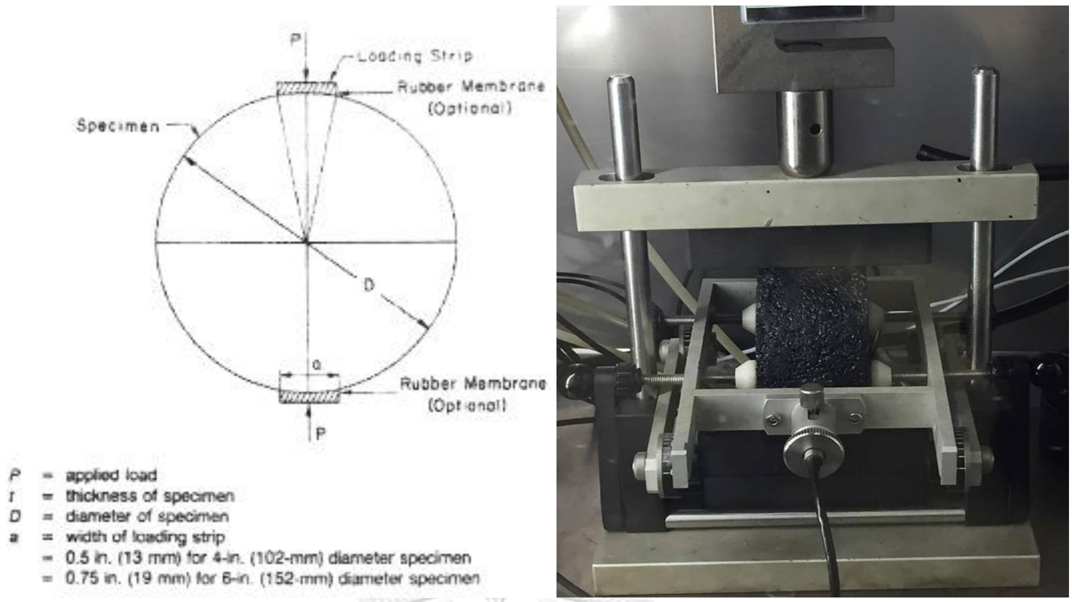

Figure 4. 5 The indirect tension test for resilient modulus (ASTM, 1995)

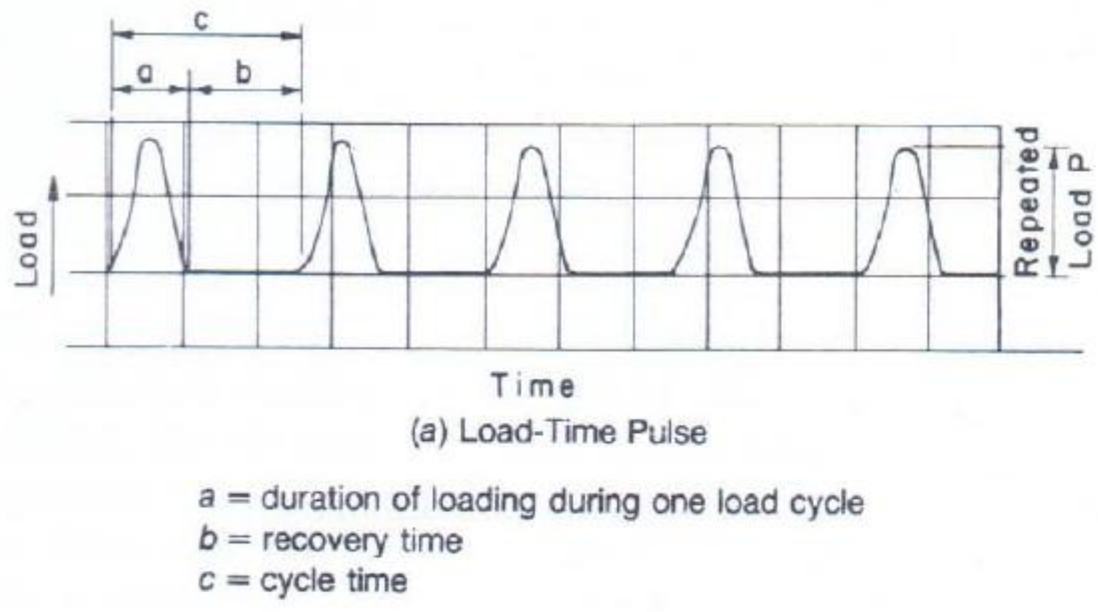

Figure 4. 6 The characteristic of pattern load for indirect tension test for resilient modulus (ASTM, 1995)

The Indirect Tension Test for Resilient Modulus was found the modulus recovery of specimens by following the standard ASTM D4123-82 (1995): Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures(ASTM, 1995). This test was the repeated load while the damages from repeated load did not destroy the characteristic material. The behavior of pressure was shown in the figure 4.6 at the frequency of test by the accumulated pressure in each specimen range 50-200 cycles for the smooth surface and collapse specimen in horizontal. Then, the continuous procedure pressured more 5 last cycles and recorded the 5 cycle's values to find the average resilient modulus values of specimen. After that, the procedure rotated the specimen in 90°C and continued the test again. The resilient modulus value was the average of 5 cycles in both direction of specimen. This test had the details and limitations below:

- The pressure of resilient modulus test is limited to 10% of the indirect tensile strength based on the test result shown in the figure 4.4, which had the approach indirect tensile strength value. Therefore, the procedure test fixed the repeated load with 10% of the minimum indirect tensile strength as 750N to load all specimens in each treatment.
- Controlling the Poisson Ratio to calculate the dimension change value of specimen by 0.35.
- The loading frequency was 1.0 Hz.
- At 3 levels of temperature test was 25, 37.5 and 50 °C

For the result of Indirect Tension Test for resilient modulus in all treatments was shown in the figure 4.7 – 4.11 below:

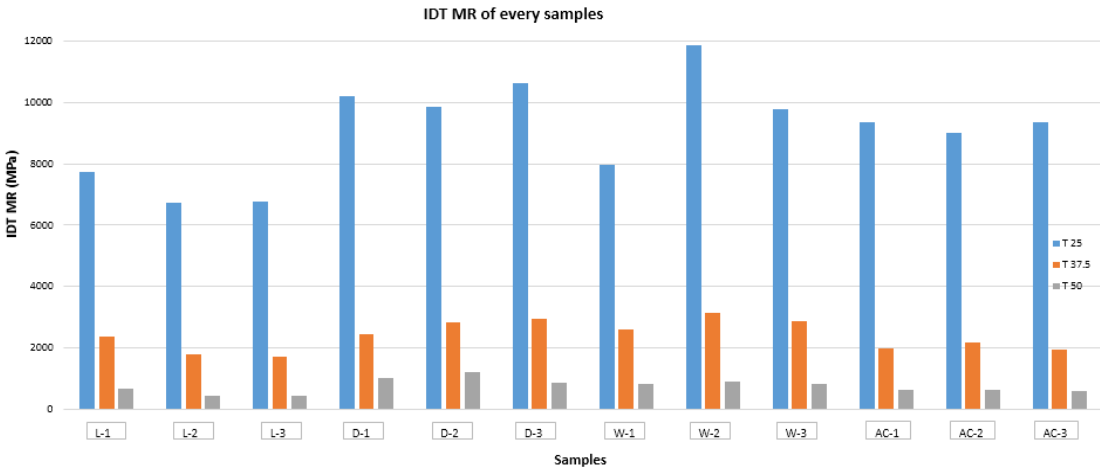

Figure 4. 7 The resilient modulus values for every samples

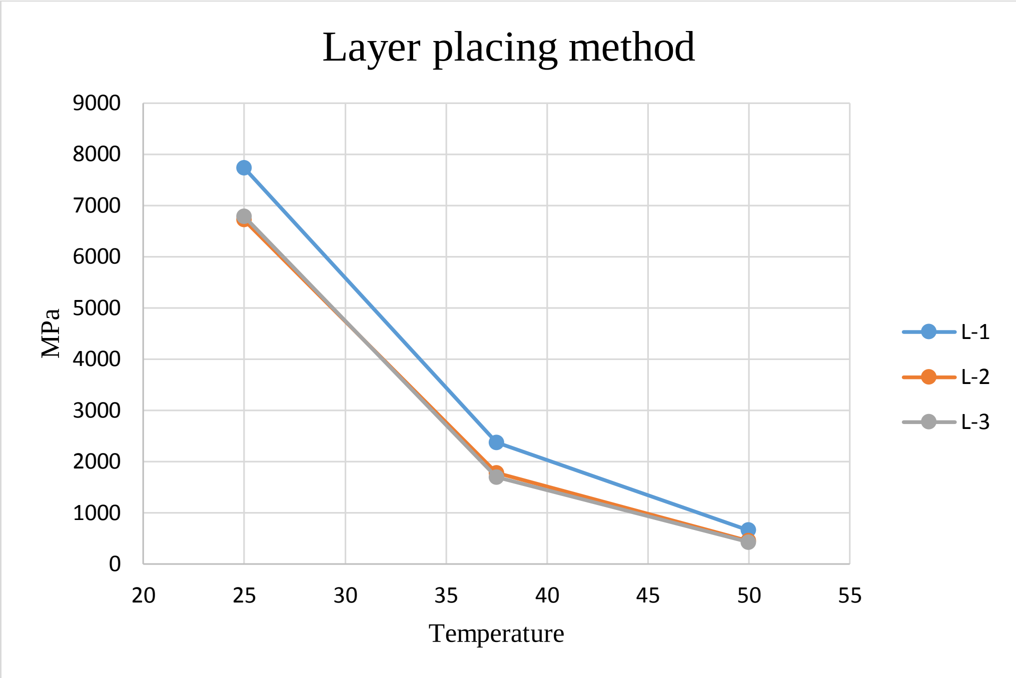

Figure 4. 8 The resilient modulus values for layer placing method.

This figure had shown the test result of resilient modulus with the layer placing method at the temperature 25ºC, 37.5 ºC and 50 ºC.

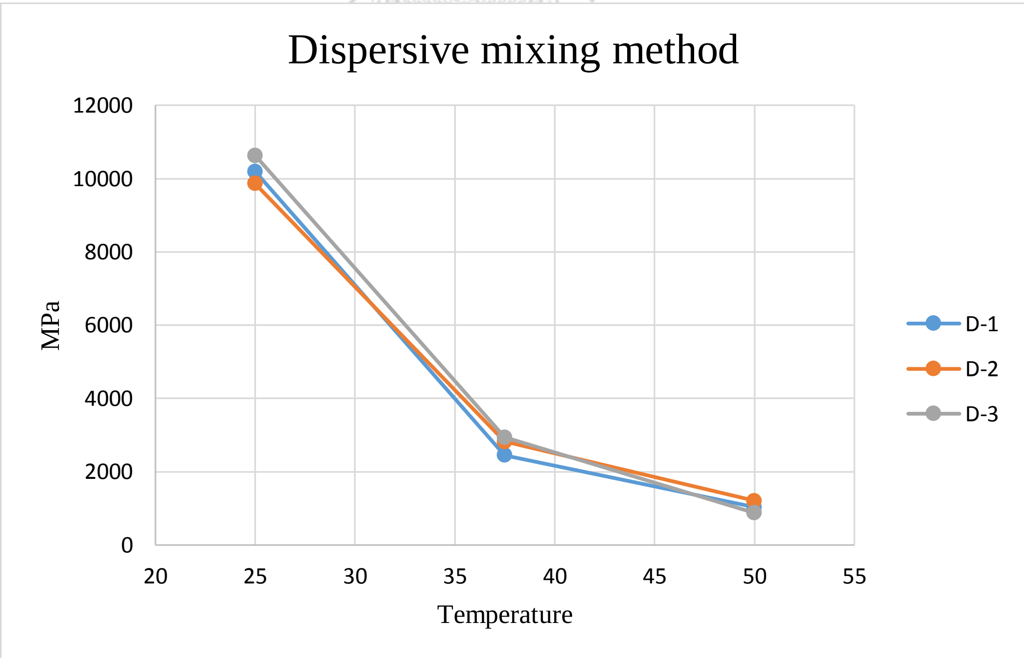

Figure 4. 9 The resilient modulus values for dispersive mixing method.

This figure had shown the test result of resilient modulus with the dispersive mixing method at the temperature 25ºC, 37.5 ºC and 50 ºC.

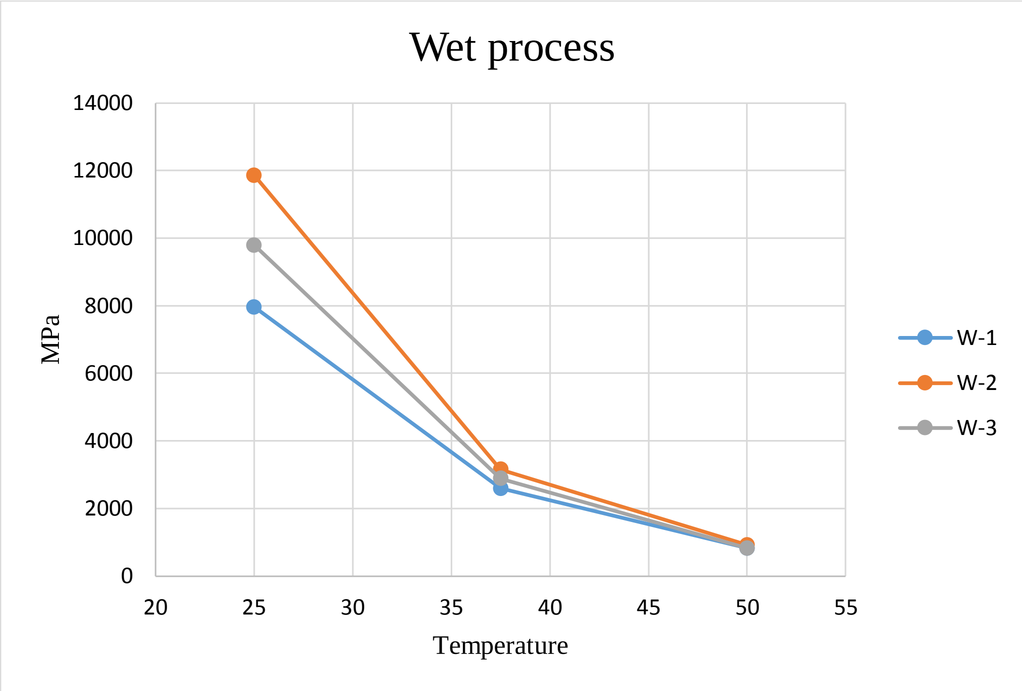

Figure 4. 10 The resilient modulus values for wet process.

This figure had shown the test result of resilient modulus with the wet process at the temperature 25ºC, 37.5 ºC and 50 ºC.

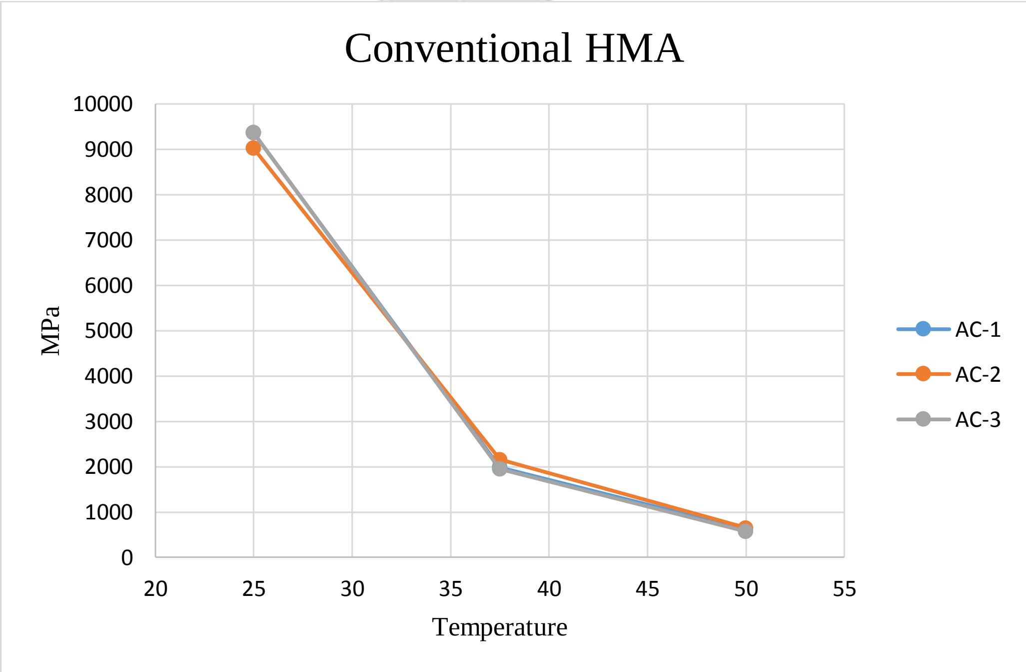

Figure 4. 11 The resilient modulus values for conventional HMA.

This figure had shown the test result of resilient modulus with the conventional HMA at the temperature 25ºC, 37.5 ºC and 50 ºC.

Table 4. 7 The summary of resilient modulus test at each level of temperature

Samples	Average MR @ Temp			Remark
	25 ºC	37.5 ºC	50 ºC	
L-1	7732	2369.5	659	Layer placing method
L-2	6717	1779.5	452	
L-3	6786	1696	422.5	
D-1	10193	2448	1027.5	Dispersive mixing method
D-2	9864.5	2823	1204	
D-3	10636.5	2939.5	875	
W-1	7959	2596.5	822.5	Wet process
W-2	11858.5	3156.5	920.5	
W-3	9789.5	2887.5	828.5	
AC-1	9365	1986	616	Conventional HMA
AC-2	9025.5	2157	650.5	
AC-3	9365.5	1950	575	

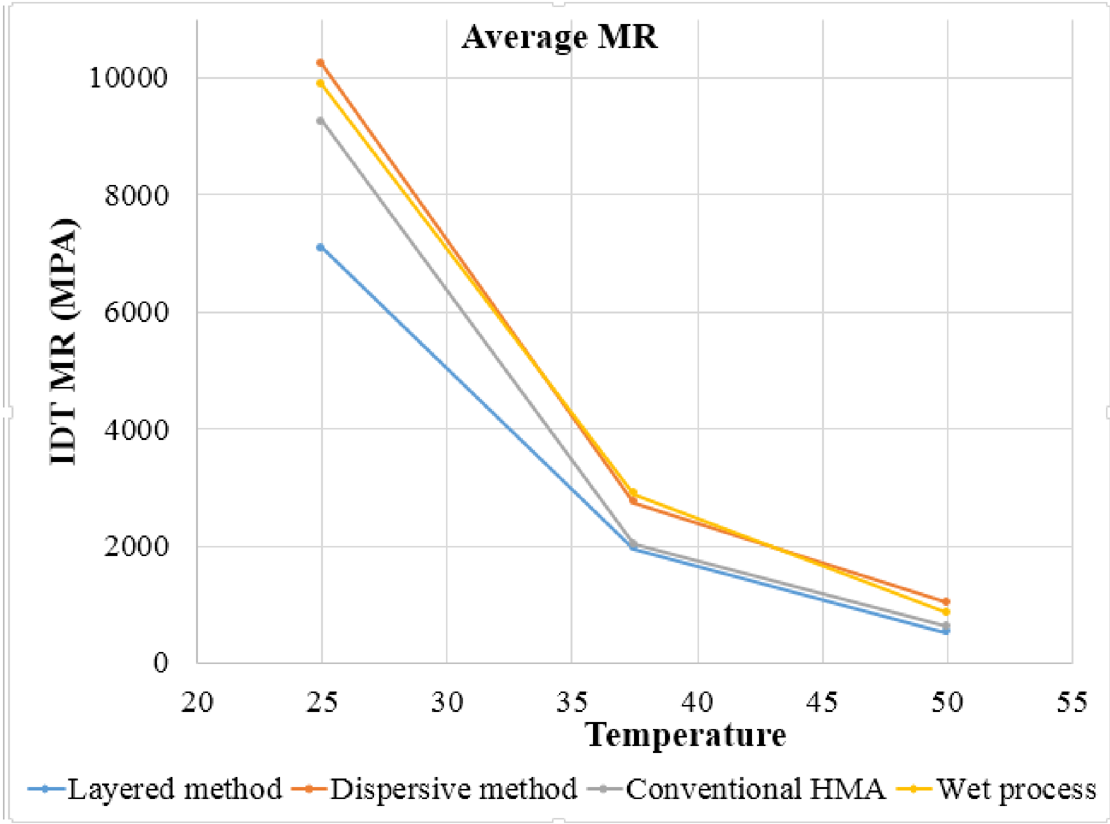

Figure 4. 12 The average resilient modulus values for 4 treatments

From the figure 4.12, the result represented the difference of resilient modulus values in each treatment and divided in 2 groups of result for resilient modulus values. In the three levels of temperature test had the details to explain each treatment below:

- At 25 ºC, crumbed para rubber added by layer placing method resulted in substantially lower resilient modulus comparing to the conventional HMA and the other treatment cases.
- At 37.5 ºC, the specimens prepared by the wet process and the dispersive mixing method had higher resilient modulus values than those prepared by the layer placing method and conventional HMA.
- At 50 ºC, the dispersive mixing method had shown the highest modulus value than the conventional HMA and layer placing method. The wet process had the second higher resilient modulus.

In overall, the dispersive mixing method and the wet process had consistently increased the resilient modulus of the conventional HMA significantly

For checking the test results, this research used the SPSS program to compare all treatments with the statistical analysis as One-way ANOVA. One-way ANOVA is used to determine the statistically significant differences between means of two groups or moreover. In addition, there had 4 treatments group , 3 level testing and 12 samples in each level testing. That is shown on the table 4.8.

Table 4. 8 The comparison of 4 treatments group in three level temperature.

Methods	**After screening**	**MR** (MPa) **at 25ºC**	**MR** (MPa) **at 37.5ºC**	**MR** (MPa) **at 50ºC**
Layer placing method	3	L-1 =7732	L-1 = 2369.5	L-1 = 659
		L-2 = 6717	L-2 = 1779.5	L-2 = 452
		L-3 = 6786	L-3 = 1696	L-3 = 422.5
Dispersive mixing method	3	D-1 = 10193	D-1 = 2448	D-1 = 1027.5
		D-2 = 9864.5	D-2 = 2823	D-2 = 1204
		D-3 = 10636.5	D-3 = 2939.5	D-3 = 875
Wet process	3	W-1 = 7959	Wet-1 = 2596.5	Wet-1 = 822.5
		W-2 = 11858.5	Wet2 = 3156.5	Wet-2 = 920.5
		W-3 = 9789.5	Wet-3 = 2887.5	Wet-3 = 828.5
Conventional HMA	3	AC-1 = 9365	AC-1 = 1986	AC-1 = 616
		AC-2 = 9025.5	AC-2 = 2157	AC-2 = 650.5
		AC-3 = 9365.5	AC-3 = 1950	AC-3 = 575

Null hypothesis H_0: $\mu_{Layer} = \mu_{Dispersive} = \mu_{Wet} = \mu_{AC}$

Alternative hypothesis H_1: $\mu_i \neq \mu_j$ for at least one pair ($i \neq j$)

In assumption of ANOVA, this research is selected the confidently interval range at 90%, the null hypothesis were the 4 treatments case have the same mean and the alternative hypothesis were the 4 treatments case have the difference mean for at least one pair on each level testing. The analysis of One-way ANOVA is shown on the table 4.9.

Table 4. 9 One-way ANOVA

		Sum of Squares	df	Mean Square	F	P value
MR 25ºC	Between Groups	1794843.333	3	5981281.111	5.543	0.024
	Within Groups	8632980.833	8	1079122.604	-	-
	Total	26576824.167	11	-	-	-
MR 37.5 ºC	Between Groups	2052531.417	3	684177.139	9.391	0.005
	Within Groups	582824.000	8	72853.000	-	-
	Total	2635355.417	11	-	-	-
MR 50 ºC	Between Groups	505498.917	3	168499.639	13.994	0.002
	Within Groups	96325.500	8	12040.688	-	-
	Total	601824.417	11	-	-	-

Remark: P value $\leq \alpha$=0.1

After analysis of One-way ANOVA, the result in Table 4.14 shows the P-value of 0.024 at 25 ºC, P-value of 0.005 at 37.5 ºC and P-value of 0.002 at 50 ºC. There are significantly lower than 0.1 at 90% confident interval. This means the result rejects null hypothesis and accept alternative hypothesis. Although the result of Resilient Modulus in 4 treatments group were difference value, but that did not show the treatments be different. Therefore, this research continued to Multiple Comparison Test by LSD methods (Least Significant Difference) for checking which treatments were different Resilient Modulus value. That is indicated on the table 4.10.

Table 4. 10 Multiple Comparisons

Dependent Variable	(I) group	(J) group	Mean Difference (I-J)	Std. Error	P value	90% Confidence Interval	
						Lower Bound	Upper Bound
MR 25ºC	Layer	Dispersive	-3153*	848	0.006	-4730.24	-1575.76
		Wet	-2791*	848	0.011	-4367.90	-1213.43
		AC	-2174*	848	0.034	-3750.90	-596.43
	Dispersive	Wet	362	848	0.681	-1214.90	1939.57
		AC	979*	848	0.282	-579.90	2556.57
	Wet	AC	617*	848	0.488	-960.24	2194.24
MR37.5ºC	Layer	Dispersive	-788.500*	220.383	0.007	-1198.31	-378.69
		Wet	-931.833*	220.383	0.003	-1341.65	-522.02
		AC	-82.667	220.383	0.717	-492.48	327.15
	Dispersive	Wet	-143.333	220.383	0.534	-553.15	266.48
		AC	705.833*	220.383	0.013	296.02	1115.65
	Wet	AC	849.167*	220.383	0.005	439.35	1258.98
MR 50ºC	Layer	Dispersive	-524.333*	89.594	0.000	-690.94	-357.73
		Wet	-346.000*	89.594	0.005	-512.60	-179.40
		AC	-102.667	89.594	0.285	-269.27	63.94
	Dispersive	Wet	178.333*	89.594	0.082	11.73	344.94
		AC	421.667*	89.594	0.002	255.06	588.27
	Wet	AC	243.333*	89.594	0.026	76.73	409.94

Remark: P value $\leq \alpha=0.1$

At 25 ºC, there had 5 pairs be the P value smaller than α value that meant 5 pairs had the different Resilient Modulus value. The result are shown the dispersive mixing method was the highest resilient modulus values that increased 11% of resilient modulus values by comparison with the conventional HMA and the dispersive mixing method increased 45% of resilient modulus by comparison with the layer placing method. The second higher resilient modulus value was the wet process, which increased 39% of resilient modulus values by comparison with the layer placing method. On the other hand, the conventional HMA increased 31% of resilient modulus values by comparison with the crumbed para rubber added by layer placing method.

At 37.5 ºC, there had 4 pairs be the P value smaller than α value that meant 4 pairs had the different Resilient Modulus value. The result are shown the specimens prepared by the wet process and the dispersive mixing method had higher resilient modulus values than those prepared by the layer placing method and conventional HMA. Both the wet process and the dispersive mixing method increased 42% and 35% of resilient modulus values by comparison with the conventional HMA. Furthermore, Both the wet process and the dispersive mixing method increased 48% and 40% of resilient modulus values by comparison with the layer placing method.

At 50 ºC, At 25 ºC, there had 5 pairs be the P value smaller than α value that meant 5 pairs had the different Resilient Modulus value. The result are shown the dispersive mixing method had shown the highest resilient modulus value than the conventional HMA and layer placing method. The wet process had the second higher resilient modulus. Furthermore, the dispersive mixing method increased 69% of resilient modulus a part form the wet process increased 40% of resilient modulus by comparison with the conventional HMA. Moreover, both dispersive mixing method and wet process increased 103% and 68% of resilient modulus by comparison with the layer placing method. Finally, the dispersive mixing method increased 21% of resilient modulus by comparison with the wet process.

In summary, the Multiple Comparison Test by LSD methods represented both the dispersive mixing method and the wet process had consistently increased the resilient modulus than the conventional HMA and the layer placing method significantly. In short, the dispersive mixing method and the wet process had the highest resilient modulus values by comparison with other treatments.

4.4 Dynamic Creep

Dynamic Creep Test was the resistance to permanent deformation test of asphalt concrete. This test determined the minimum stain rate and the corresponding number of cycles. Furthermore, this test simulated the behavior of traffic load similarly the accumulated strains at some point in pavement within the duration of time. The test procedure followed the Australian Standard test AS 2891.12.1-1995: Methods of sampling and testing asphalt; Method 12.1: Determination of the permanent compressive strain characteristics of asphalt-Dynamic creep test (Australian, 1995) that had the condition below:

- Air voids (AV)	5.0 ±0.5%
- Test temperature	50 ±0.5ºC
- Compressive stress	200±5 kPa
- Loading period t_1	0.5 ±0.05 s
- Pulse repetition period t_p	2.0 ±0.05 s

The procedure compacted the specimens by gyratory compactor to control the specimens with 5% air voids, 50 mm of height and the density of specimens was the same value of indirect tensile strength test above. The characteristic of vertical loading force was the waveform similarly the rectangular with the space of duration time as 0.5 second of interval load and 1.5 second of period in the next load that shown in the figure 4.13. In addition, the vertical loads of trapezoidal shape are applied to the specimen repeatedly until 20,000 cycles with 11.11 hours of duration or the permanent vertical strain exceeds 30,000 micro strains that were tested by the Universal Testing Machine. The characteristic of Dynamic Creep Test represented the minimum strain rate in which cycles that shown in figure 4.14.

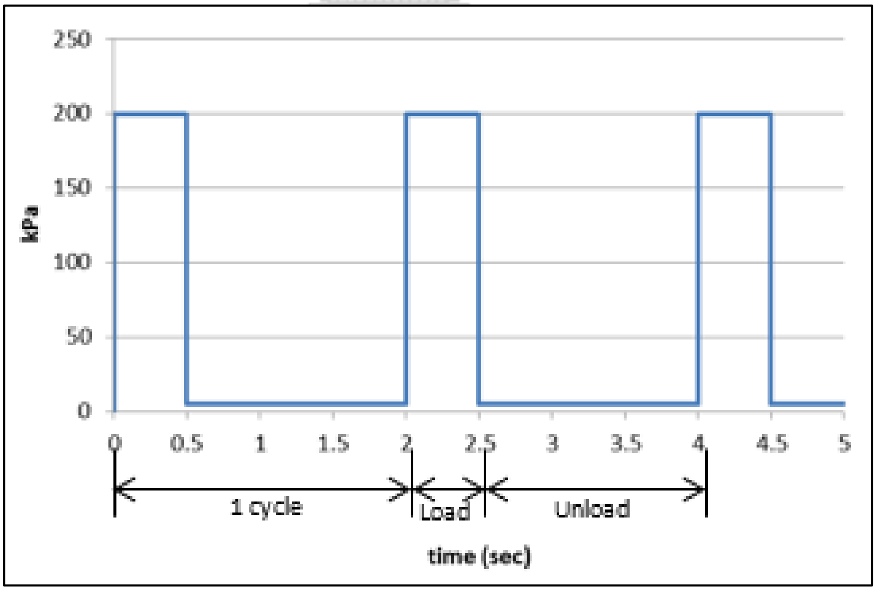

Figure 4. 13 The characteristic of load pattern for Dynamic creep test

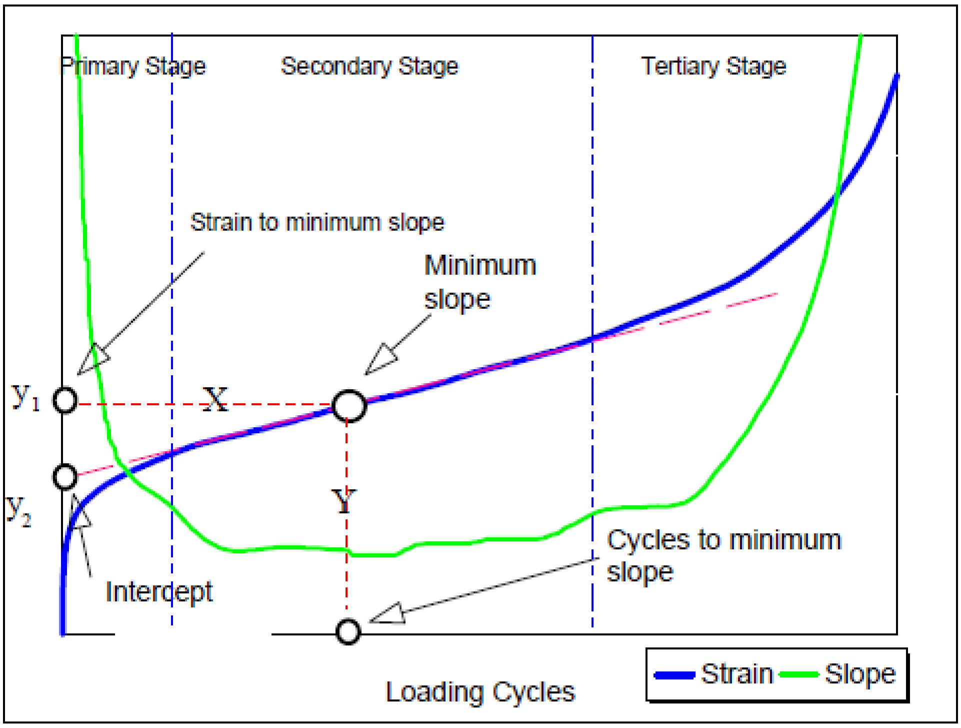

Figure 4. 14 Typical Dynamic Creep curve including slope curve (Alderson, 2008)

Figure 4. 15 The Universal Testing Machine (UTM)

After proceeding test, the minimum strain rate and the number of circles, the Australian Standard had set the criteria for determining the resistance permanent deformation of asphalt concrete mixture, which can support the level of traffic volume or classified the level of traffic volume. It's called the Weighted Mean Annual Pavement Temperature (WMAPT)> 30ºC that accorded the weather condition of Thailand similarly Department of Highway (DOH).

Table 4. 11 The Weighted Mean Annual Pavement Temperature (WMAPT)> 30ºC (Alderson, 2008)

WMAPT (ºC)	**Traffic**			
	Very heavy	**Heavy**	**Medium**	**Light**
> 30	< 0.5	0.5 to 3	> 3 to 6	Not applicable
20-30	< 1	1 to 6	> 6 to 10	
10-20	< 2	2 to 10	Not applicable	

The traffic category is explained below:

- Very Heavy: free flowing traffic volume > 2×10^7 ESA (>1000 commercial vehicles per day per lane)
- Heavy: free flowing traffic volume in the range 5×10^6 to 2×10^7 ESA (500 to 1000 commercial vehicles per day per lane)
- Medium: free flowing traffic volume in the range 5×10^5 to 5×10^6 ESA (100 to 500 commercial vehicles per day per lane)
- Light: free flowing traffic volume <5×10^5 ESA (<100 commercial vehicles per day per lane)

For the result of Dynamic Creep test was shown in the figure 4.16, the figure 4.17, the figure 4.18 and the table 4.13.

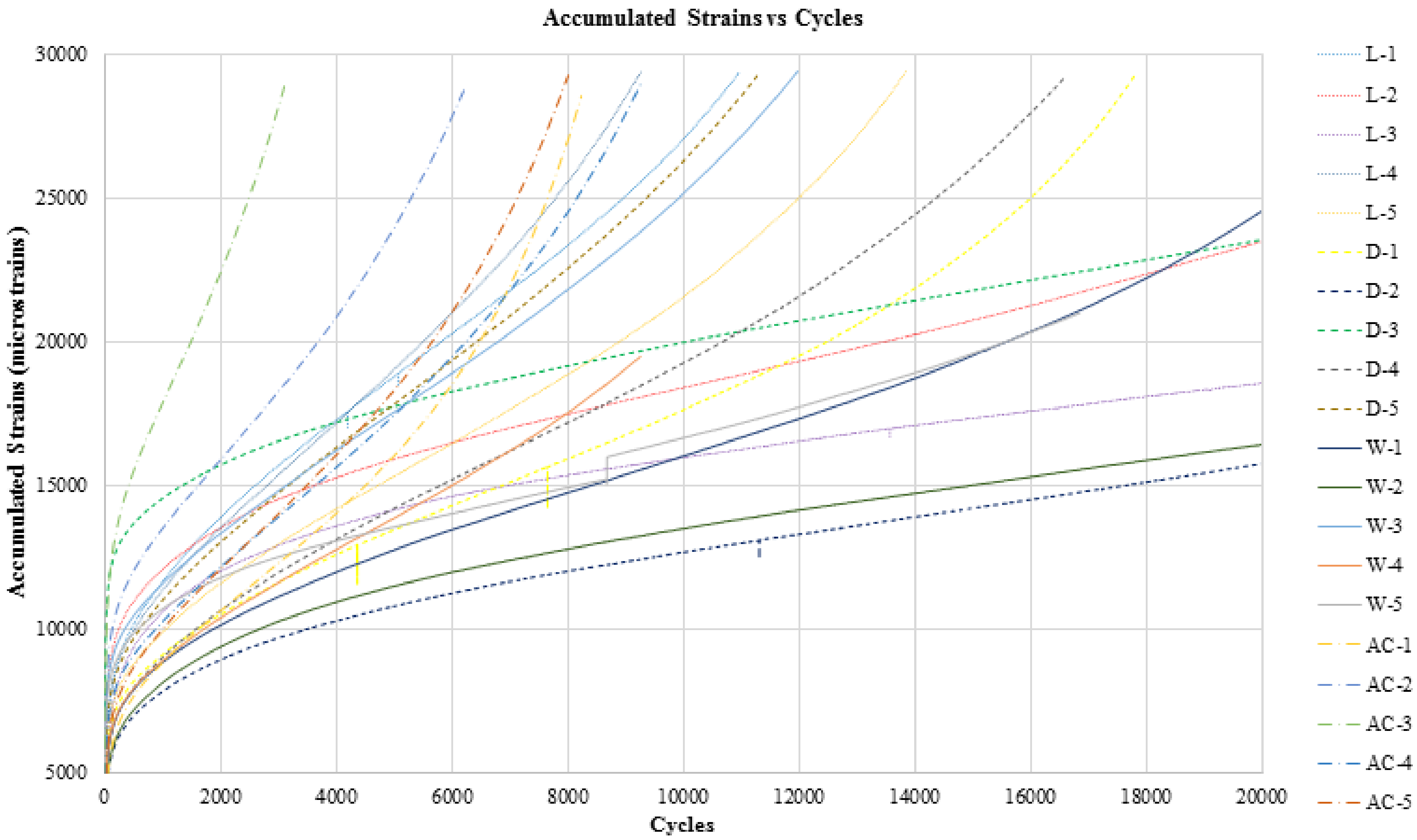

Figure 4. 16 The relationship between the accumulated strains and the cycles test

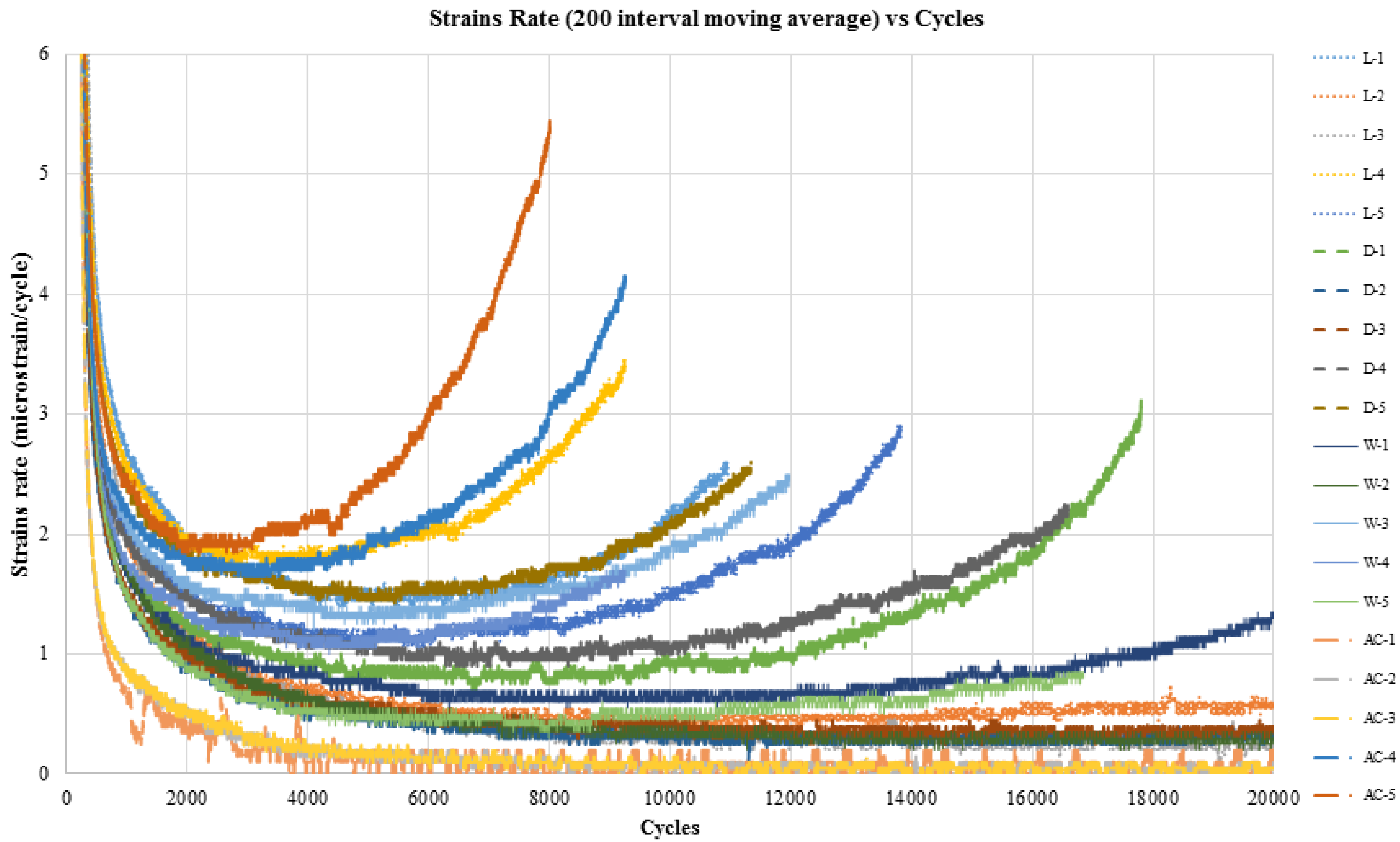

Figure 4. 17 The relationship between strains rate and the cycles test

Table 4. 12 The summary of Dynamic Creep test

Samples	Binder	Min Strain rate	Cycle @min strain rate	Traffic level @30°C WMAPT
Layered CPR-1	2%NR by total weight be layer	1.5	5000	Heavy
Layered CPR-2		0.5	10000	Very Heavy
Layered CPR-3		0.2	20000	Very Heavy
Layered CPR-4		1.8	3400	Heavy
Layered CPR-5		1.2	5000	Heavy
Dispersive CPR-1	2%NR by total weight during mix	0.8	7200	Heavy
Dispersive CPR-2		0.3	14400	Very Heavy
Dispersive CPR-3		0.3	16800	Very Heavy
Dispersive CPR-4		1.0	7200	Heavy
Dispersive CPR-5		1.5	5000	Heavy
Wet-1	wet process	0.6	10000	Heavy
Wet-2		0.3	18800	Very Heavy
Wet-3		1.4	5000	Heavy
Wet-4		1.3	4000	Heavy
Wet-5		0.3	7500	Very Heavy
AC-1	AC 60/70	1.6	3100	Heavy
AC-2		2.4	2000	Heavy
AC-3		4.4	1400	Medium
AC-4		1.6	3750	Heavy
AC-5		2.1	2000	Heavy

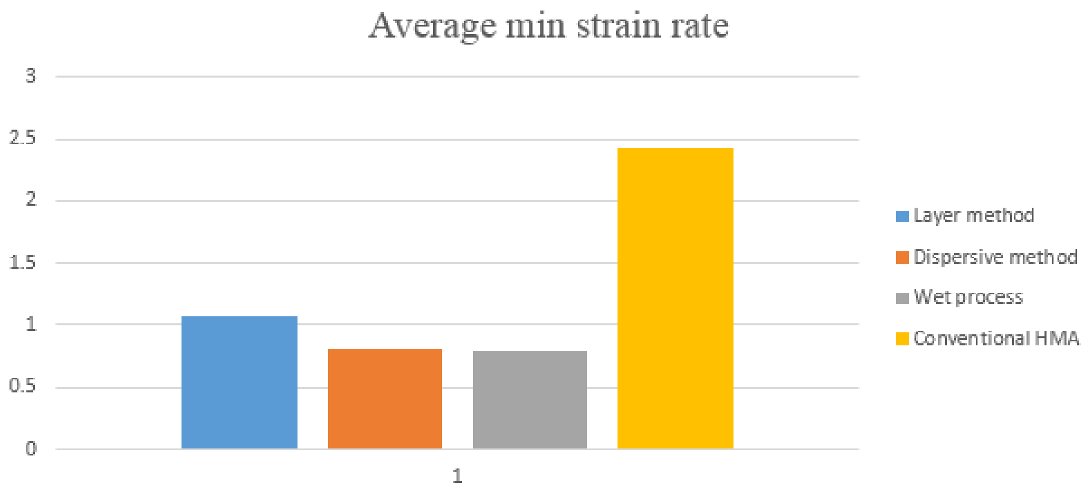

Figure 4. 18 The average minimum strain rate

From the test results shown, all of the para rubber modified asphalt concrete cases fall into the traffic level between heavy and very heavy whereas the conventional HMA falls into the traffic level between medium and heavy. Moreover, the para rubber modified asphalt concrete cases were the longer cycles test than the conventional HMA. In addition, some samples test had the lower minimum strain rate mean the good properties of resistance deformation and some samples test had the longer cycles mean the ability of loading time or long service life. In short, the para rubber modified asphalt concrete cases had the higher resistance of permanent deformation than the conventional HMA.

For verifying the influences of parameters on the test results, this research used the SPSS program to perform analysis of variance (ANOVA) to compare all treatments with the statistical analysis as One-way ANOVA. One-way ANOVA is used to determine the statistically significant differences between means of two groups or moreover. From laboratory tests, this research had 4 treatments group and 20 samples. They are shown on the figure 4.19, the figure 4.20, the figure 4.21 and the figure 4.22.

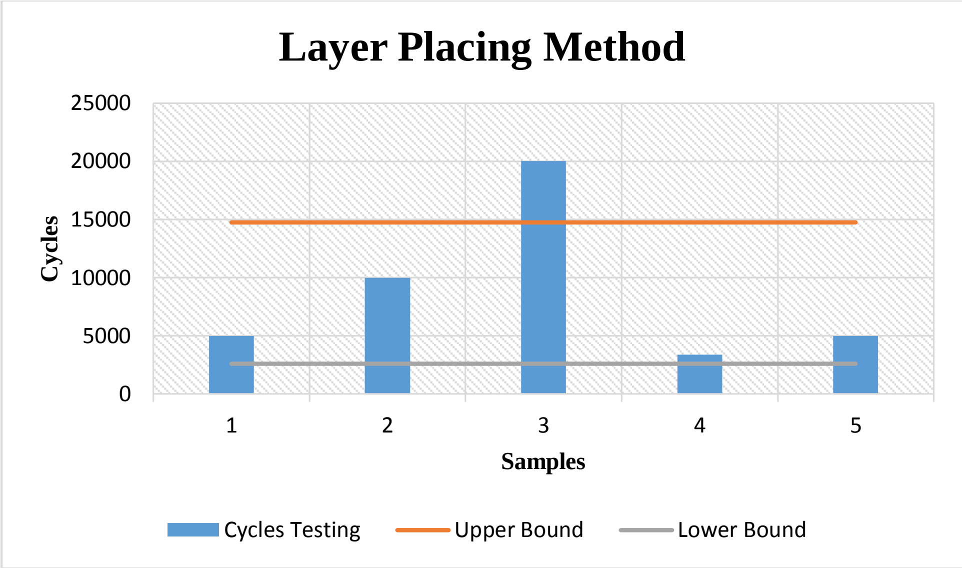

Figure 4. 19 The cycles testing of layer placing method

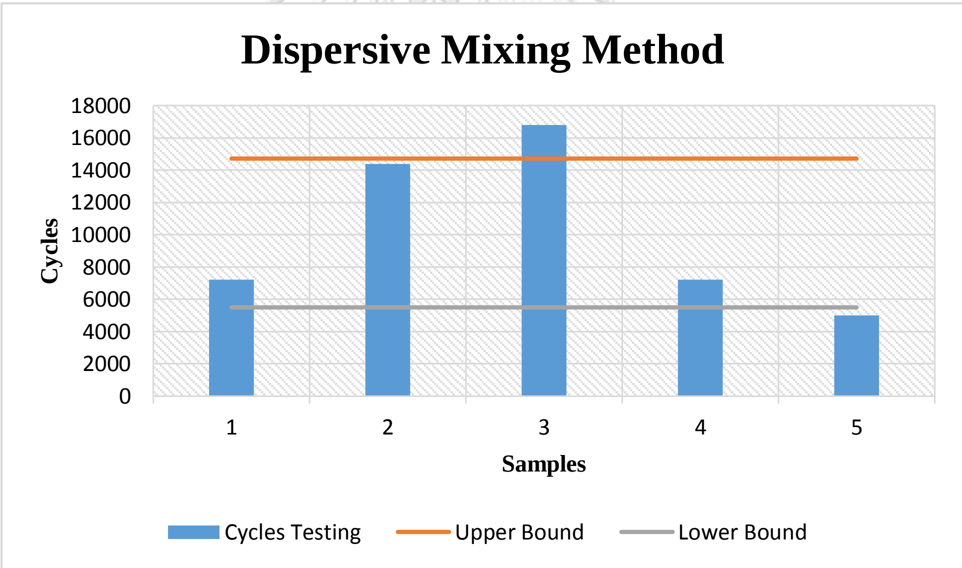

Figure 4. 20 The cycles testing of dispersive mixing method

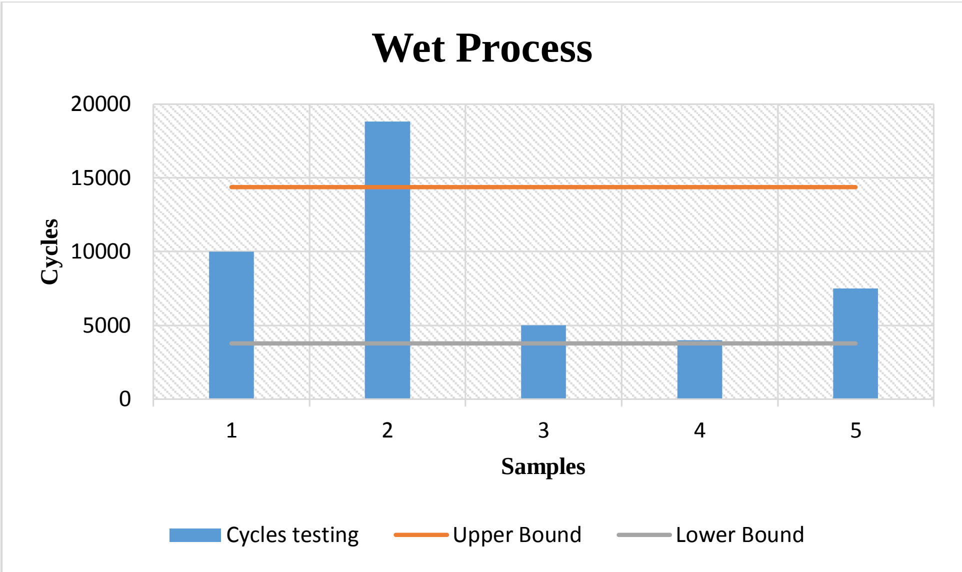

Figure 4. 21 The cycles testing of wet process

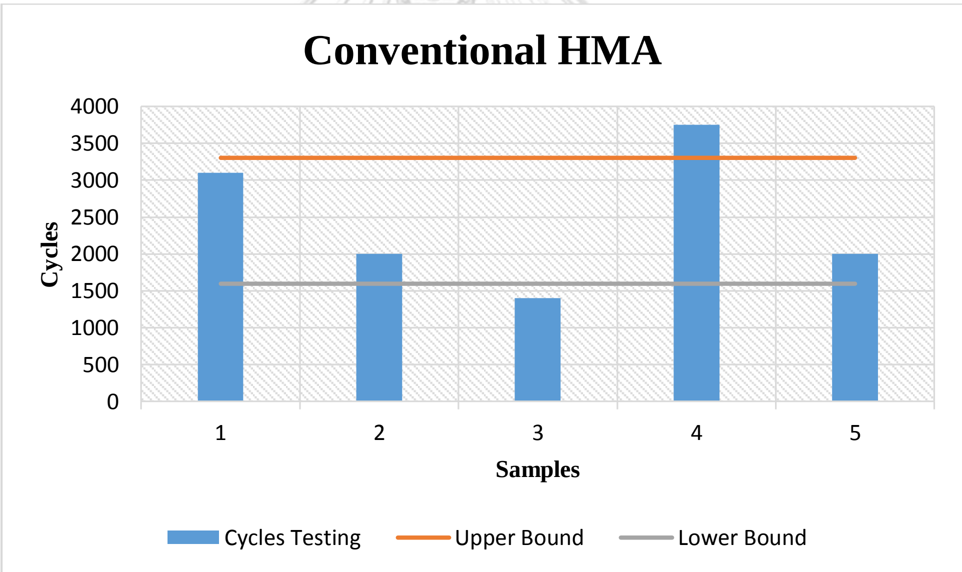

Figure 4. 22 The cycles testing of conventional HMA

In those plots, some results were found much higher or lower than others. To reduce the bias from the outlier results, this research used only 14 samples to perform One-way ANOVA because there were results of 6 samples over boundary values by assumption range between mean plus standard deviation and mean minus standard deviation. The results are shown on the table 4.13.

Table 4. 13 The comparison of 4 treatments group

Methods	After Screening	Cycles testing
Layer mixing method	4	L-1 = 5000 cycles
		L-2 = 10000 cycles
		L-3 = 3400 cycles
		L-5 = 5000 cycles
Dispersive mixing method	3	D-1 = 7200 cycles
		D-2 = 14400 cycles
		D-4 = 7200 cycles
Wet Process	4	W-1 = 10000 cycles
		W-3 = 5000 cycles
		W-4 = 4000 cycles
		W-5 = 7500 cycles
Conventional HMA	3	AC-1 = 3100 cycles
		AC-2 = 2000 cycles
		AC-5 = 2000 cycles

Null hypothesis H_0: $\mu_{Layer} = \mu_{Dispersive} = \mu_{Wet} = \mu_{AC}$

Alternative hypothesis H_1: $\mu_i \neq \mu_j$ for at least one pair ($i \neq j$)

In assumption of ANOVA, this research is selected the confidently interval range at 90%. The null hypothesis were the 4 treatment cases have the same means and the alternative hypothesis were the 4 treatment cases have the different means for at least one pair. The analysis of One-way ANOVA is shown on the table 4.14 as below:

Table 4. 14 One-way ANOVA

	Sum of Squares	df	Mean Square	F	P value
Between Group	7954619.048	3	26515873.016	3.403	0.061
Within Groups	77921666.667	10	7792166.667	-	-
Total	157469285.714	13	-	-	-

Remark: P value $\leq \alpha$=0.1

After analysis of One-way ANOVA, the result in Table 4.14 shows the P-value of 0.061, which is significantly lower than 0.1 at 90% confident interval. This means the result rejects null hypothesis and accept alternative hypothesis. Although the result of cycles test in 4 treatments group were difference value, but that did not show the treatments be different. Therefore, this research continued to Multiple Comparison Test by LSD methods (Least Significant Difference) for checking which treatments were different Resilient Modulus value. That is shown on the table 4.15.

Table 4. 15 Multiple Comparisons

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	P value	90% Confidence Interval	
					Lower Bound	Upper Bound
Layer	Dispersive	-3525.000	2132.002	0.129	-7389.17	339.17
	Wet	-550.000	1973.850	0.786	-4127.53	3027.53
	AC	3708.333	2132.002	0.113	-155.84	7572.50
Dispersive	Wet	2975.000	2132.002	0.193	-889.17	6839.17
	AC	7233.333*	2279.206	0.010	3102.36	11364.30
Wet	AC	4258.333*	2132.002	0.074	394.16	8122.50

Remark: P value ≤ α=0.1

From the LSD test, there had 2 pairs be the P value smaller than α value that meant 2 pairs had the different cycles test. The result is shown that in the dispersive mixing method and the wet process, the number of cycle's increase 313% and 270% that means both treatments had the longer service life and the higher resistance deformation than the conventional HMA.

CHAPTER V
CONCLUSION

This research summarized the conclusion in two topics as a summary of research and the recommendation below.

5.1 Summary of Research

This research focuses on the improvement properties of asphalt concrete as the resistance to permanent deformation by using crumbed para rubber replacing some aggregate in hot mix asphalt with the dry process. The related parameters of testing were controlled such as crumbed para rubber with size passing # 4 sieve and retained #8 sieve and fixed the amount with 2% by total volume of aggregate. Moreover, there were 4 experimental treatments including the dispersive mixing method, the layer placing method, the wet process and the conventional hot mix asphalt.

The dispersive mixing method and the layer placing method implemented the crumbed para rubber with 2% by total volume of aggregate. The wet process used the para rubber latex with 5% by asphalt binder weight and the conventional hot mix asphalt did not use the crumbed para rubber or latex to modify the properties of asphalt concrete. After that, this research proceeded to design the asphalt concrete mixture according to Marshall Mix design method. The results of Marshall Test, all treatments passed the base condition of Marshall as the stability and flow and the percent air void. Next, this research continued to test the Indirect Tensile Strength for finding which treatment was the strength of asphalt concrete. Moreover, this research preceded the Resilient Modulus test that shown the elastic recovery of asphalt concrete by using 10% of Indirect Tensile Strength test. Lastly, the Dynamic Creep test represented the resistance permanent deformation of asphalt concrete.

The Indirect Tensile Strength (ITS) test results represented the strength of asphalt concrete as the dispersive mixing method had the highest test result than the other treatments and increased 9% of ITS by comparing with the conventional hot mix asphalt.

The Resilient Modulus Test results revealed that the dispersive mixing method and the wet process were better in elastic recovery than the conventional HMA at all levels of temperature (25, 37.5 and 50 ºC). The dispersive mixing method increased 11% of resilient modulus at temperature 25 ºC, 35% at temperature 37.5 ºC and 69% at temperature 50 ºC. In the same way, the wet process increased 42% of resilient modulus at temperature 37.5 ºC and 40% at temperature 50 ºC. That result meant the para rubber modifier had increased the properties of asphalt concrete as elastic modulus significantly.

The Dynamic Creep Test represented the resistance permanent deformation in asphalt concrete as the simulation the real traffic or the behavior traffic loading on the surface road. The test results showed that all of the para rubber modifier cases had the lower minimum strain rate than the conventional HMA which meant para rubber modifier cases had the higher performance of resistance to permanent deformation in asphalt concrete. Moreover, the dispersive mixing method and the wet process had the longer cycles test than the conventional HMA that meant both dispersive mixing method and wet process had the better resistance to repeated loading times or increased service life. In short, the dispersive mixing method increased 313% and the wet process increased 270% of service life by comparison with the conventional HMA.

Considering the structural performance of pavement, there are two mixing methods as the dispersive mixing method and the wet process that perform the best of the group in increasing the engineering properties of asphalt concrete such as the strength, elastic modulus and deformation resistance. However, there are other aspects that should be also considered as follows:

- The quantity of para rubber: the dispersive mixing method used crumbed para rubber to modify the asphalt concrete by adding 2% of total aggregate volume or 0.8% of total mixture weight. In contrast, the wet process used 5% of total asphalt cement weight or 0.16% of total mixture weight to modify asphalt concrete. After comparison, that was shown the dispersive mixing method using the higher amount of crumbed para rubber than the wet process to modify asphalt concrete.

- The convenience in the construction site: the dispersive mixing method was the easily mixing on the blend before transport to construction site as crumbed para rubber particles were mixed with HMA in a mixer during the post hot mixing process. On the other hand, the wet process had the many steps to proceed in construction site as this process was added para latex on the asphalt cement for modify asphalt cement before mixture. Furthermore, the wet process used a long time for stirring asphalt cement in the mixing, had the short time in construction site because asphalt cement modifier para latex had the high cooling and viscosity when the temperature decreased. Therefore, the dispersive mixing method was more convenient in construction process, probably lower construction cost and easier production than the wet process.

5.2 Recommendation

In the recommendation part, this research had the 3 treatments modifier with para rubber that can improve the asphalt concrete in the reality construction site and had the difference in pavement construction aspect as below:

The layer placing method is the most convenient way to add crumbed para rubber into asphalt concrete pavement because it requires no additional equipment and the amount of rubber can be measured at site. Although the performance of this method is not comparable to the other methods, further study on influence of more crumbed para rubber with layer placing method may be conducted.

The wet process is the existing method to modify asphalt concrete in Thailand. This method requires additional equipment and care on blending para rubber latex into asphalt cement and stirring the asphalt binder during transportation to the hot mix plant. Furthermore, this method has the higher cost comparing to the other methods.

The dispersive mixing method has the most benefits including higher content of crumbed para rubber into HMA comparing to the wet process, ease of mixing process in hot mix plant, and slightly better performance comparing to the wet process.

Furthermore, a study on price comparison between the dispersive mixing method and the wet process in construction is recommended to and know the different price between the wet process and dry process.

Finally, the para rubber modifier asphalt concrete is an alternative to reduce the amount of asphalt cement in the construction road because the asphalt cement was made by the refinery of crude oil. Therefore, this asphalt concrete modifier is worth to stimulate the consumption of para rubber in Thailand.

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APPENDIX

❖ Resilient Modulus

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ONEWAY MR25 MR37 MR50 BY group
  /STATISTICS DESCRIPTIVES
  /MISSING ANALYSIS
  /POSTHOC=LSD ALPHA(0.1).
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One-way

Descriptive

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
MR 25 ºC	Layer	3	7078.33	567.142	327.440	5669.47	8487.19	6717	7732
	Dispersive	3	10231.33	387.425	223.680	9268.92	11193.75	9865	10637
	Wet	3	9869.00	1950.965	1126.390	5022.53	14715.47	7959	11859
	HMA	3	9252.00	196.155	113.250	8764.72	9739.28	9026	9366
	Total	12	9107.67	1554.373	448.709	8120.07	10095.27	6717	11859
MR 37.5 ºC	Layer	3	1948.33	367.123	211.958	1036.35	2860.32	1696	2370
	Dispersive	3	2736.83	256.830	148.281	2098.83	3374.83	2448	2940
	Wet	3	2880.17	280.072	161.700	2184.43	3575.90	2597	3157
	HMA	3	2031.00	110.594	63.851	1756.27	2305.73	1950	2157
	Total	12	2399.08	489.467	141.297	2088.09	2710.08	1696	3157
MR 50 ºC	Layer	3	511.17	128.874	74.406	191.03	831.31	423	659
	Dispersive	3	1035.50	164.646	95.058	626.50	1444.50	875	1204
	Wet	3	857.17	54.930	31.714	720.71	993.62	823	921
	HMA	3	613.83	37.797	21.822	519.94	707.73	575	651
	Total	12	754.42	233.904	67.522	605.80	903.03	423	1204

ANOVA

		Sum of Squares	df	Mean Square	F	P value
MR25ºC	Between Groups	17943843.333	3	5981281.111	5.543	0.024
	Within Groups	8632980.833	8	1079122.604	-	-
	Total	26576824.167	11			
MR37.5ºC	Between Groups	2052531.417	3	684177.139	9.391	0.005
	Within Groups	582824.000	8	72853.000	-	-
	Total	2635355.417	11		-	-
MR50ºC	Between Groups	505498.917	3	168499.639	13.994	0.002
	Within Groups	96325.500	8	12040.688	-	-
	Total	601824.417	11	-	-	-

Post Hoc Tests

Multiple Comparisons

LSD

Dependent Variable	(I) group	(J) group	Mean Difference (I-J)	Std. Error	Sig.	90% Confidence Interval	
						Lower Bound	Upper Bound
MR25ºC	Layer	Dispersive	-3153.000*	848.183	0.006	-4730.24	-1575.76
		Wet	-2790.667*	848.183	0.011	-4367.90	-1213.43
		HMA	-2173.667*	848.183	0.034	-3750.90	-596.43
	Dispersive	Layer	3153.000*	848.183	0.006	1575.76	4730.24
		Wet	362.333	848.183	0.681	-1214.90	1939.57
		HMA	979.333	848.183	0.282	-597.90	2556.57
	Wet	Layer	2790.667*	848.183	0.011	1213.43	4367.90
		Dispersive	-362.333	848.183	0.681	-1939.57	1214.90
		HMA	617.000	848.183	0.488	-960.24	2194.24
	HMA	Layer	2173.667*	848.183	0.034	596.43	3750.90
		Dispersive	-979.333	848.183	0.282	-2556.57	597.90
		Wet	-617.000	848.183	0.488	-2194.24	960.24
MR37.5ºC	Layer	Dispersive	-788.500*	220.383	0.007	-1198.31	-378.69
		Wet	-931.833*	220.383	0.003	-1341.65	-522.02
		HMA	-82.667	220.383	0.717	-492.48	327.15
	Dispersive	Layer	788.500*	220.383	0.007	378.69	1198.31
		Wet	-143.333	220.383	0.534	-553.15	266.48
		HMA	705.833*	220.383	0.013	296.02	1115.65
	Wet	Layer	931.833*	220.383	0.003	522.02	1341.65
		Dispersive	143.333	220.383	0.534	-266.48	553.15
		HMA	849.167*	220.383	0.005	439.35	1258.98
	HMA	Layer	82.667	220.383	0.717	-327.15	492.48
		Dispersive	-705.833*	220.383	0.013	-1115.65	-296.02
		Wet	-849.167*	220.383	0.005	-1258.98	-439.35
MR50ºC	Layer	Dispersive	-524.333*	89.594	0.000	-690.94	-357.73
		Wet	-346.000*	89.594	0.005	-512.60	-179.40
		HMA	-102.667	89.594	0.285	-269.27	63.94
	Dispersive	Layer	524.333*	89.594	0.000	357.73	690.94
		Wet	178.333*	89.594	0.082	11.73	344.94
		HMA	421.667*	89.594	0.002	255.06	588.27
	Wet	Layer	346.000*	89.594	0.005	179.40	512.60
		Dispersive	-178.333*	89.594	0.082	-344.94	-11.73
		HMA	243.333*	89.594	0.026	76.73	409.94
	HMA	Layer	102.667	89.594	0.285	-63.94	269.27
		Dispersive	-421.667*	89.594	0.002	-588.27	-255.06
		Wet	-243.333*	89.594	0.026	-409.94	-76.73

*. The mean difference is significant at the 0.1 level.

❖ Dynamic Creep

ONEWAY Creep BY Group
/STATISTICS DESCRIPTIVES
/MISSING ANALYSIS
/POSTHOC=LSD ALPHA(0.1).

Oneway

Descriptives

Creep

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Layer	4	6075.00	2637.391	1318.696	1878.32	10271.68	4300	10000
Dispersive	3	9600.00	4156.922	2400.000	-726.37	19926.37	7200	14400
Wet	4	6625.00	2688.711	1344.355	2346.66	10903.34	4000	10000
HMA	3	2366.67	635.085	366.667	789.03	3944.31	2000	3100
Total	14	6192.86	3480.377	930.170	4183.35	8202.37	2000	14400

ANOVA

Creep

	Sum of Squares	df	Mean Square	F	P value
Between Groups	79547619.048	3	26515873.016	3.403	0.061
Within Groups	77921666.667	10	7792166.667	-	-
Total	-	-	-	-	-

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Creep

LSD

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	90% Confidence Interval	
					Lower Bound	Upper Bound
Layer	Dispersive	-3525.000	2132.002	0.129	-7389.17	339.17
	Wet	-550.000	1973.850	0.786	-4127.53	3027.53
	HMA	3708.333	2132.002	0.113	-155.84	7572.50
Dispersive	Layer	3525.000	2132.003	0.129	-339.17	7389.17
	Wet	2975.000	2132.002	0.193	-889.17	6839.17
	HMA	7233.333*	2279.206	0.010	3102.36	11364.30
Wet	Layer	550.000	1973.850	0.786	-3027.53	4127.53
	Dispersive	-2975.000	2132.002	0.193	-6839.17	889.17
	HMA	4258.333*	2132.002	0.074	394.16	8122.50
HMA	Layer	-3708.333	2132.002	0.113	-7572.50	155.84
	Dispersive	-7233.333*	2279.206	0.010	-11364.30	-3102.36
	Wet	-4258.333*	2132.002	0.074	-8122.50	-394.16

*. The mean difference is significant at the 0.1 level.

VITA

Mr. Hatthaphone Silimanotham was born on 22 July 1993 at Vientiane Capital, Lao PDR. In 2011, I graduated the secondary school at Lycee de Vientiane. In 2015, I graduated the Bachelor's degree at the National University of Laos with road-bridge and transportation engineering major. After that, I continued to study the Master's degree at Civil Engineering Department, Faculty of Engineering, Chulalongkorn University, Thailand. Since 2015 until 2017 study at Chulalongkorn University, I have had the scholarship to support the payment and the collaborative research budget that scholarship was AUN/Seed-Net. In the future, I will be a teacher or a government official to support my country leaving the poor development country