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# THE MODIFICATION OF ASPHALT WITH NATURAL RUBBER LATEX

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**Abstract** : The purpose of this research is to study the engineering properties of asphalt cement and asphalt concrete mixtures with natural rubber in form of concentrated latex as additives. It also emphasizes on determining the optimum proportion of concentrated latex to be used in the mixing process. In this research, Natural Rubber Asphalt (NRA) obtained from mixing AC 60/70 with High Ammonia (HA) concentrated latex at the content of 1-13 percent by total weight were used to mix with limestone to produce asphalt concrete samples. The results showed that NRA binders outperformed conventional asphalt cement in term of engineering properties. It can be concluded from this research that the use of natural rubber latex as additive is the best alternative. Due to its domestic availability, natural rubber is more suitable for road making in the natural rubber producing countries and to the fact that the utilized natural rubber as additives tend to improve flexibility and stability of asphalt pavement and bringing greater service life expectancy. The suggested proportion of concentrated latex in blending with asphalt cement is 9 percent by total weight.

**Keyword** : Concentrated latex, Asphalt cement, Binders, Asphalt concrete mixtures, Performance test

## 1. INTRODUCTION

The rapid growth of cities in recent years resulted in a lot of transportation. Road surface have experienced a significant increase of traffic flows and carrying loads. In tropical countries, the normal temperature in summer time will make the asphalt material become softer. This will also reduce the service life of the road. In Thailand, most of highway networks made from asphalt concrete are easily damaged due to hot climate. The two main damages are permanent deformation and fatigue cracking. This made highway engineers realized about the methodology to solve these problems. Therefore, we selected to consider the issue of improving qualities and properties of asphalt materials by using domestic additives.

Natural rubber is considered to be a significant economic plant in Thailand as Thailand is the number one producer and exporter of natural rubber in the world. Since 1997 until recent years, there was a global economic crisis. The world demand and production of natural rubber were imbalanced. The natural rubber producing countries have many problems such as price fluctuations and overcapacity of supplies during economic crisis. The reduction in domestic prices of natural rubber resulted in marketing intervention by the Thai government that used a huge amount of budget to maintain natural rubber prices. However, such action was merely a short-term solution. It did not help raising the level of natural rubber prices. Therefore, the long-term solution is to increase domestic consumption as much as possible in order to add value to domestic natural rubber products.

The application of natural rubber by mixing with asphalt materials in roadwork is an alternative material that may help increase domestic consumption of natural rubber. Furthermore, such application could improve the quality of road pavement, extend service life of the road, and reduce expenditures in maintaining road pavement.

Natural Rubber is classified as high molecular weight hydro-carbon polymer materials which has chemical structure as “cis 1,4 Polyisoprene” and a chemical formula as “$C_5H_8$”. The remarkable qualifications of natural rubber are elasticity, ability to stand high tension, and resiliency. This is due to a lot of complex molecular chains which form strong bonds and structure.

In this research, natural rubber latex was selected for mixing with asphalt materials because mixing with natural rubber latex provide the most efficient product compared with other form of rubber in equal quantity (Smith, 1960). The changing properties in viscous, elastic and brittle were considered. We provide the relationship between softening point and various types of rubber added as shown in Figure 1. Note that natural rubber latex has the lowest cost and could be easily procured.

Natural Rubber Latex can be divided into two types: field latex and concentrated latex. Field latex can be obtained by ripping natural rubber tree which has approximately 35 percent of Dry Rubber Content (DRC), and the remaining is water. Field latex could maintain its condition shortly after ripping (no more than three hours). Then it will coagulate as gel before spoiling. Another type of natural rubber latex is concentrated latex which is obtained by adding chemical substance such as Ammonia into field latex in order to preserve latex condition. Then water part is separated to get 60 percent dry rubber content by centrifuging. If it uses Ammonia to preserve latex condition 0.7 percent per rubber weight, it calls “High Ammonia (HA)” while using Ammonia to preserve latex condition 0.2 percent per rubber weight call “Low Ammonia (LA)”.

Therefore, we decided to use concentrated latex in mixing with asphalt materials since it has dry rubber content more than field latex. Moreover, concentrated latex can be stored longer. Furthermore, the mixing process resulted in less foaming and frothing than field latex due to water content in latex. These helps increase safety and ease the mixing process.

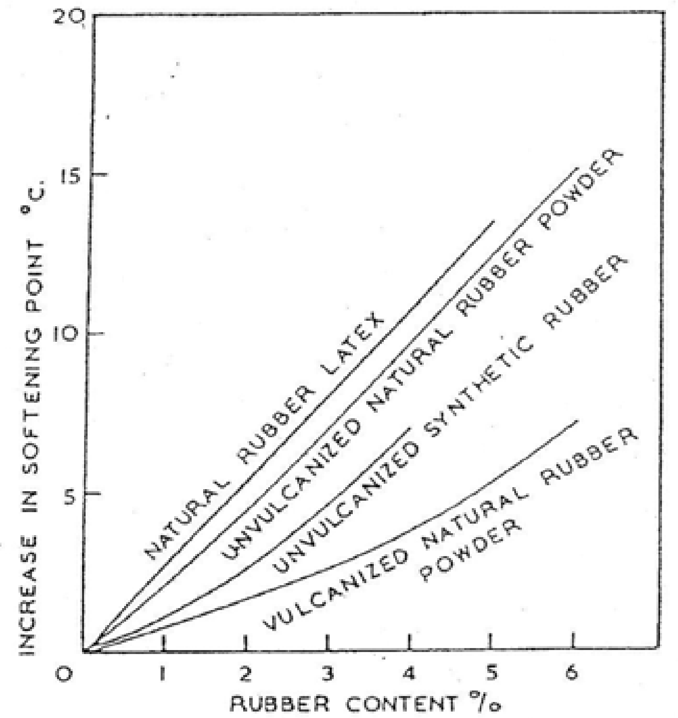


**Figure 1. The Effect of Blending Different Forms of Rubber on the Softening Point of AC 90/100**

## 2. EXPERIMENTAL PROGRAM

### 2.1. Materials

1. Asphalt Cement grade 60/70 (AC 60/70)
2. Natural rubber in form of concentrated latex with high ammonia (HA) which results from centrifuging to gain 60 percent of dry rubber content (DRC)
3. Limestone that has properties and gradation according to the specification of Department of Highways (DOH) in designing asphalt concrete wearing courses for 12.5 millimeter nominal size of aggregates.

In this research, concentrated latex was incorporated into AC 60/70 at the content of 1, 3, 5, 7, 9, 11 and 13 percent by total weight.

### 2.2. Preparation of Blends

1. Preparation of Natural Rubber Asphalt (NRA) started from heating asphalt cement with hot plate at temperature about 140 – 150$^{o}$C. The quantity of asphalt in blending container should have at least 2/3 of blending container to allow room for the increase of blends and foaming which occurs as the water in the latex evaporates. Then asphalt cement is stirred with the high shear rate mechanical mixer in 5,000 rpm speed.
2. When rubber latex was added into hot asphalt cement directly, foaming and frothing occur uncontrollably. Care must be exercised against excessive and potentially dangerous foaming as water evaporates from the hot mixture (Mullins, 1971). It should be careful when adding large amount of concentrated latex since there is almost 40 percent of water in concentrated latex and the temperature of blending is higher than the boiling point of water. The procedure

recommended is that the latex should be added gradually to the surface of the asphalt. Mixing concentrated latex with asphalt cement as shown in Figure 2 is blending slowly about 2-3 milliliter per minute. The water in latex should flash off and wait until the residual latex that floats on the surface for about 20 seconds before being drawn down under. It needs to blend the NRA mixture throughout the mixing process and maintain stable mixing temperature.

**Figure 2. The Rubberized Asphalt Mixing Process**

3. Stirring should be continued about 20 – 30 minutes after addition of rubber latex and maintain the temperature level in stability for homogeneity of the NRA binders (Fernando *et al.*, 1969). This can be observed from the morphology of NRA binders with 40 times enlarging power microscope as shown in Figure 3. If properly mixed, the particle of rubber will spread as small points throughout asphalt cement.

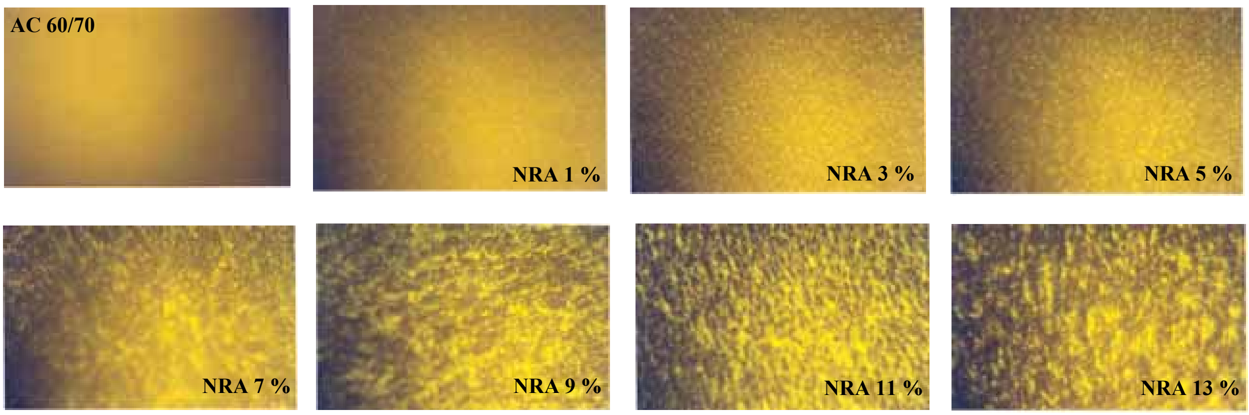


**Figure 3. The Morphology of NRA Binders with 40X Enlargement**

Mixing high content of concentrated latex would result in the NRA binder becoming more viscous and less homogeneous. From the morphology, it can see that the particle of rubber that spreads in the NRA binder became larger and rougher. Therefore, when it mixed with high content of concentrated latex, it needs to increase the mixing temperature so the NRA binder is liquidated enough to provide homogeneity. This also allows the NRA binder to have viscosity close to that of the asphalt concrete mixing process between asphalt materials and aggregates (170 ± 20 centipoises) as shown in Figure 4. This is a guideline for using temperature in mixing NRA binders in different proportion with aggregates to make asphalt concrete mixtures.

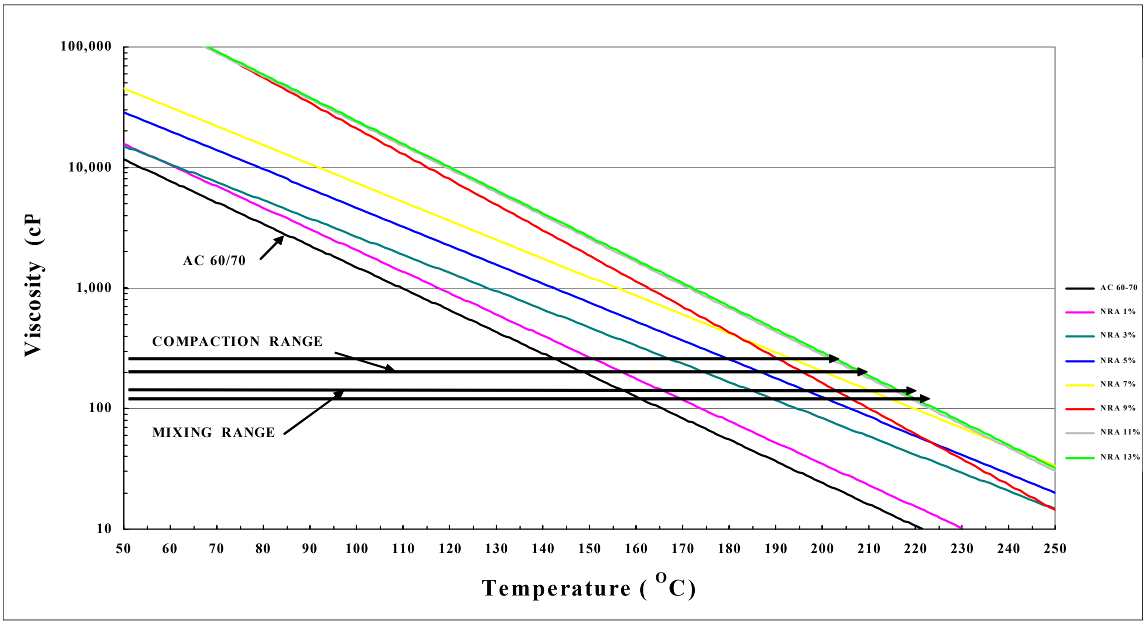


**Figure 4. The Relationship between Temperature and Viscosity of NRA Binders**

Since mixing process utilizes high temperature with prolonged period of heating, the quality of NRA binders may decrease. Therefore, at the beginning of mixing process, it should be avoid to heat asphalt cement higher than 175$^{o}$C as asphalt may experience aging and degradation. Furthermore, while mixing of concentrated latex, we have to control temperature to be no more than 270$^{o}$C since temperature higher than this point can cause degradation for natural rubber (Hamdan *et al.*, 2000). Natural rubber will breakdown immediately during 360 – 380$^{o}$C (Turi, 1981).

In addition to some suggestions regarding the preparation and storage of the NRA binders is also important. If we store the NRA binders at high temperature, they will degrade rapidly. Thus, time and temperature for storage of the NRA binders should follow allowable storage times suggested in Table 1 (Thompson, 1964). The NRA binders needed to be slightly stirred before use to prevent binder segregation.

**Table 1. Allowable Storage Times for Natural Rubber Asphalt**

| Temperature ($^{o}$C) | Storage times |
|---|---|
| Room temperature | Unlimited |
| 120 | 7 days |
| 130 | 3 days |
| 140 | 2 days |
| 150 | 18 hours |
| 160 | 12 hours |
| 170 | 4 hours |
| 180 | 3 hours |
| 200 | 1 hour |

## 3. TESTING METHODOLOGY

### 3.1. Binders Testing

Both AC 60/70 and NRA binders in different proportions will be tested according to the details mentioned in Table 2.

**Table 2. Binders Testing Program**

| Item | Properties | Unit | Test Method |
|---|---|---|---|
| 1 | Penetration at 25 $^{o}$C, 100 g , 5 sec. | 0.1 mm | ASTM D5 |
| 2 | Softening point, Ring and Ball | $^{o}$C | ASTM D36 |
| 3 | Penetration Index | - | NLT-181 |
| 4 | Ductility at 13 $^{o}$C, 5 cm/min | cm | ASTM D113 |
| 5 | Ductility at 25 $^{o}$C, 5 cm/min | cm | ASTM D113 |
| 6 | Torsional recovery at 25 $^{o}$C | % | NLT-329 |
| 7 | Toughness/Tenacity test at 25 $^{o}$C | | ESM NE-31 |
| | Toughness | Kg.cm | |
| | Tenacity | Kg.cm | |
| 8 | Brookfield viscosity, Shear rate 18.6 s-1, spindle 21 | | ASTM D4402 |
| | at 135 $^{o}$C | cP | |
| | at 165 $^{o}$C | cP | |
| 9 | DSR (frequency 10 rad/sec.) at 20, 25, 30, 35, 40, 46, 52, 58, 64, 70 and 76$^{o}$C | | AASHTO TP5 |
| | G* | MPa | |
| | Phase angle | deg. | |
| **Test On Residue From Thin Film Oven Test** | | | |
| 10 | DSR (frequency 10 rad/sec.) at 20, 25, 30, 35, 40, 46, 52, 58, 64, 70 and 76$^{o}$C | | AASHTO TP5 |
| | G* | MPa | |
| | Phase angle | deg. | |
| 11 | Retained penetration at 25 $^{o}$C | % | ASTM D5 |
| 12 | Ductility at 13 $^{o}$C, 5 cm/min | cm | ASTM D113 |
| 13 | Ductility at 25 $^{o}$C, 5 cm/min | cm | ASTM D113 |
| 14 | Torsional recovery at 25 $^{o}$C | % | NTL-329 |

## 3.2. Asphalt Concrete Mixtures Testing

Each binder was compacted by Marshall Method to determine optimum binder content at 4 percent air void. Then it was compacted by Gyratory Compactor at the optimum binder content in order to provide 7 percent air void which is equivalent to air void of new road surface making. These samples will be tested according to the performance tests listed in Table 3.

**Table 3. Asphalt Concrete Mixtures Testing Program**

| Item | Description | Unit | Test Method |
|---|---|---|---|
| **1** | **Indirect Tensile Strength test (IDT)**<br>constant rate of loading 50 mm/min , at 25 $^{o}$C | MPa | AASHTO T283 |
| **2** | **Resilient Modulus (MR)**<br>using repeated 1 Hz havesine pulse loading frequency<br>(0.1 second loading period, 0.9 second rest period )<br>at 15, 25, 35 and 45 $^{o}$C, at 150 load repetitions<br>loading value 25, 20, 15 and 10 percent of IDT, respectively | MPa | AASHTO TP31 |
| **3** | **Fatigue Life**<br>using repeated 1 Hz havesine pulse loading frequency<br>(0.1 second loading period, 0.9 second rest period ), at 25 $^{o}$C<br>stress level = 0.25 MPa, at 50 percent reducing of the<br>initial MR measured after first 150 load repetitions | cycle | - |
| **4** | **Dynamic Creep test**<br>using repeated 0.5 Hz square pulse loading frequency<br>(0.5 second loading period, 1.5 second rest period ), at 50 $^{o}$C<br>stress level = 200 kPa, at accumulated strain = 1% | cycle | AS 2891.12.1 |

## 4. ANALYSIS OF RESULTS

### 4.1. Binders

Figure 5 shows relationships between binders properties and proportion of concentrated latex added into asphalt cement. The binders being tested were AC 60/70 and NRA binders.

*Penetration*

It found that when adding more concentrated latex into asphalt cement, penetration value decreased and reached the minimum value at 7 percent concentrated latex. After that penetration value tended to increase since adding more concentrated latex resulted in the binders lacked of homogeneity. Natural rubber particle layered itself above the binders surface. Such incident softens the NRA binder and resulted in a higher penetration value. At 11 percent and 13 percent concentrated latex, penetration values were higher than AC 60/70 grading criteria.

Penetration values after TFOT are provided as percentage retained. When the binder had more than 11 percent concentrated latex, retained penetration exceeded 100 percent. Retained penetration approaching 100 percent indicates that binders had the same grade even after aging. Aging makes the material becomes more brittle, less elastic, and could crack afterwards. When compared with AC 60/70, adding concentrated latex into asphalt cement could reduce aging because penetration values before and after TFOT were less different.

*Softening Point*

Softening point tends to increase by the content of concentrated latex was added. Such incident makes asphalt cement better resist deformation at high temperature as well as protects the mixture from bleeding. At 13 percent concentrated latex, softening point was 60$^{o}$C which is the maximum value that higher than AC 60/70 by 25 percent.

*Penetration Index (PI)*

Penetration Index indicates temperature susceptibility. This is a relationship between penetration value and softening point of binders. The following equation illustrates the penetration index calculation:

$$PI = \frac{20U - 300V}{U + 30V} \tag{4.1}$$

$$U = (\log 4) \times (T_{RB} - T_P) \tag{4.2}$$

$$V = \log 800 - \log P_T \tag{4.3}$$

Where

$T_{RB}$ is Softening point value ($^{o}$C)

$T_P$ is temperature of Penetration test ($^{o}$C)

$P_T$ is Penetration value at $T_P$

Road pavement material could be damaged due to ever-changing temperature. Low or negative PI value indicates high susceptibility to changes in temperature while high or positive PI value indicates that such material has low temperature susceptibility. The latter kind of material is preferred in roadwork. Generally, asphalt cement has negative PI value. It shows that adding more concentrated latex could increase PI value. It means concentrated latex helps reduce temperature susceptibility. This is due to an increase in softening point and a reduction in penetration value.

*Ductility*

Ductility was tested at 13 and 25°C both before and after TFOT. At 13°C, the test before TFOT showed that ductility tends to decrease when more than 5 percent concentrated latex was added. After TFOT, AC 60/70 had significant lower ductility because it was more brittle due to aging. This made up the distinction in ductility before and after TFOT. However, blending concentrated latex helped reduce such distinction. Ductility increases with increasing of concentrated latex content. The highest ductility occurred at 9 percent concentrated latex and it decreased when more than 9 percent concentrated latex was added due to non-homogeneity of binders. Nevertheless, such reduction in ductility still provides higher ductility than AC 60/70. Thus, mixing concentrated latex as an additive could increase ductility in asphalt cement.

At 25°C, ductility tends to decrease when more concentrated latex was added that is similar to the trend from the test at 13°C. Ductility started to decrease when more than 9 percent concentrated latex was added. Such results from both temperatures were due to the reduction in homogeneity of the mixture.

*Torsional Recovery*

Torsional Recovery is a measure of elasticity of asphalt cement. It conducted torsional recovery test at 25°C both before and after TFOT. From the test, the maximum torsional recovery occurred when 9 percent concentrated latex was added. At this point, torsional recovery was nine times higher than AC 60/70. When more than 9 percent concentrated latex was added, torsional recovery decreased slightly and remained stable. Moreover, the different value of torsional recovery between before and after TFOT still lessens. Therefore, concentrated latex can increase elasticity and reduce aging in asphalt cement.

*Toughness and Tenacity*

The test was conducted at 25°C. When compared with AC 60/70, the trend of result was similar to torsional recovery test. The maximum toughness and tenacity occurred when 9 percent concentrated latex was added. Toughness was four times higher and tenacity was seven times higher than AC 60/70. However, toughness and tenacity tended to decrease when more than 9 percent concentrated latex was added.

*Brookfield Viscosity*

It used Brookfield method to measure viscosity at 135 and 165°C. The viscosity of asphalt cement was increased with increase the content of concentrated latex. An increase in viscosity helps reduce softening and bleeding problems for asphalt materials at high temperature. It also helps strengthen adhesion with aggregates, reduce rate of stripping, and increase stability for road surface. However, workability of mixes should be cared. Therefore, viscosity in Figure 4 can be used as guideline for mixing and compacting asphalt concrete mixtures.

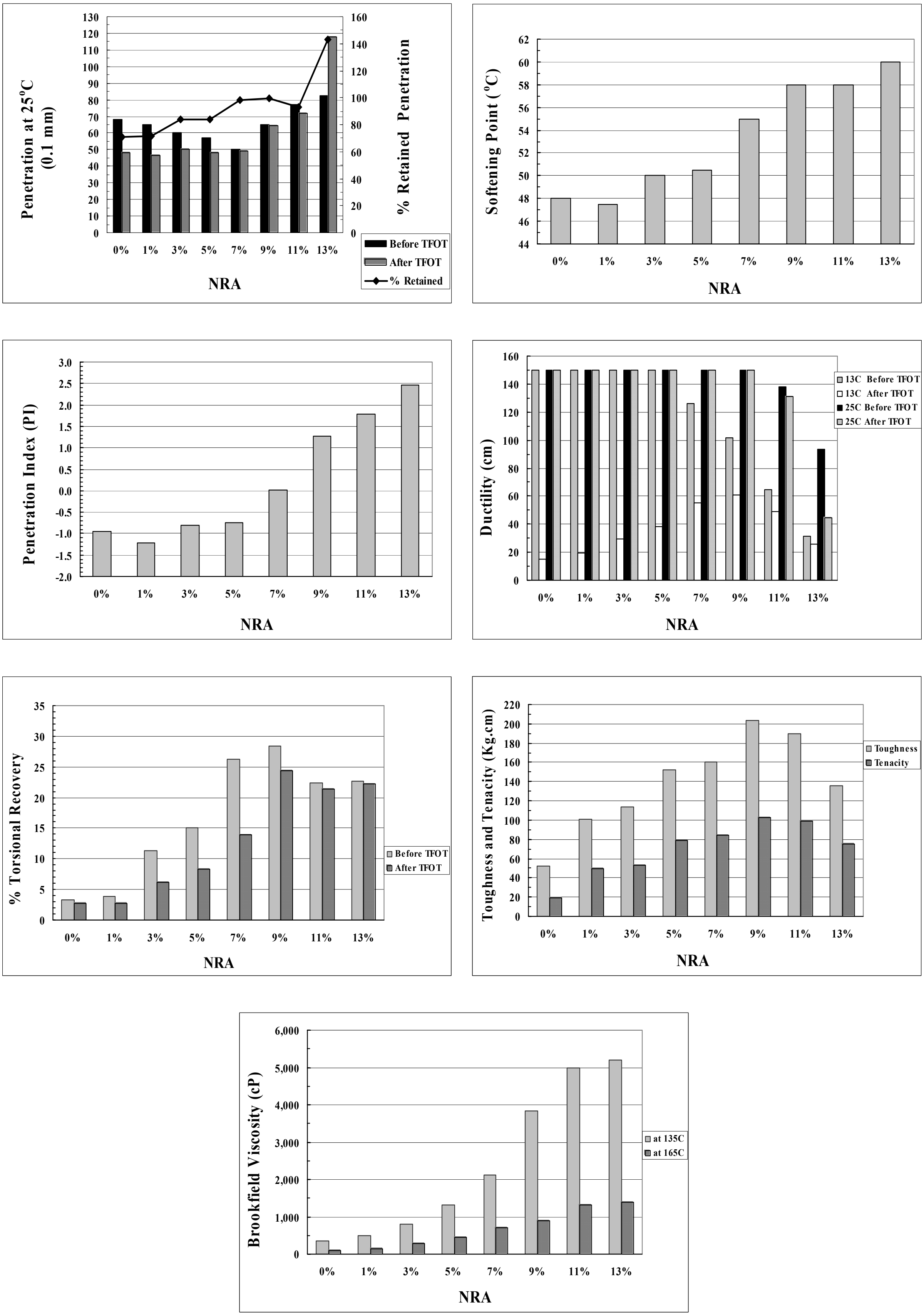


**Figure 5. Binders Properties**

It could not provide sufficient information about performance of asphalt cement by considering only the basic tests discussed earlier. The specification of Department of Highways was used to select asphalt cement for road construction by using only penetration test at 25°C. It can see that such test is only a test for stiffness in order to classify asphalt grades. In practical, service temperature might be as high as 50-60°C. Each route that used the same grade of asphalt cement might have different resistance to damage. This is because environment and temperature affect asphalt's quality.

This issue initiated research and development to test the performance of asphalt. The United States has a program to improve testing quality and design of asphalt cement and asphalt concrete called Strategic Highway Research Program (SHRP). The program initiated requirements in testing properties of asphalt and binders such as rubber, polymer, and many kinds of modified asphalt. For example, Dynamic Shear Rheometer (DSR) test is a test for rheology properties of visco-elastic materials at intermediate temperature (5-40°C) and high temperature (higher than 45°C).

Normally, asphalt is considered as a visco-elastic material. This means that it has both elastic and viscous behaviors. DSR test shows two important parameters: Complex Shear Modulus ($G^*$) and Phase Angle ($\delta$). $G^*$ refers to stiffness while $\delta$ refers to material behavior. When $\delta$ approaches zero degree, the material has elastic behavior. While $\delta$ approaches 90 degree, the material has viscous behavior. Generally, asphalt cement has $\delta$ value in 0-90 degree range. Lower temperature provides more elasticity and $\delta$ is quite low. Higher temperature provides more viscosity and $\delta$ is quite high. The behavior of material in elastic range will result in a linear $G^*$ when controlled by strain sweep control. $\delta$ is used to measure the deforming relationship between recoverable and non-recoverable.

Thus, both $G^*$ and phase angle ($\delta$) are important in designating properties of asphalt cement in order to resist road surface damages. For damages due to permanent deformation at service temperature of road surface, the specification uses $G^*/\sin\delta$ to establish an ability to resist permanent deformation. Asphalt material in general must have $G^*/\sin\delta$ more than 1.0 kPa. After short-term aging which usually happen when mixing asphalt and aggregates at high temperature, $G^*/\sin\delta$ must be no less than 2.20 kPa. Such requirement ensures that a particular asphalt materials strong enough to prevent permanent deformation at service temperature. When oxidation existed on road surface, there will be aging in asphalt materials on road surface in the long term. Fatigue cracking could happen at intermediate temperature (20-30°C) due to brittle road pavement and repetition loads. Thus, it must also check the properties of asphalt materials after aging. $G^*\sin\delta$ after aging must not exceed 5.0 MPa. These values are to ensure that asphalt materials used could resist permanent deformation and after aging will also not be more brittle that it will crack due to fatigue.

*Dynamic Shear Stiffness Test*

The test for dynamic shear stiffness used parallel plate dynamic shear rheometer. At high temperature (higher than 45°C), 25 mm. diameter plates will be used to press sample 1 mm. thick. At intermediate temperature (5-40°C), 8 mm. diameter plates will be used to press sample 2 mm. thick. The upper plate will be oscillated to provide constant stress control or constant strain control by 1.6 cycles/sec or 10 Rad/sec torque. Such torque is simulated from highway speed of 90 km/hr.

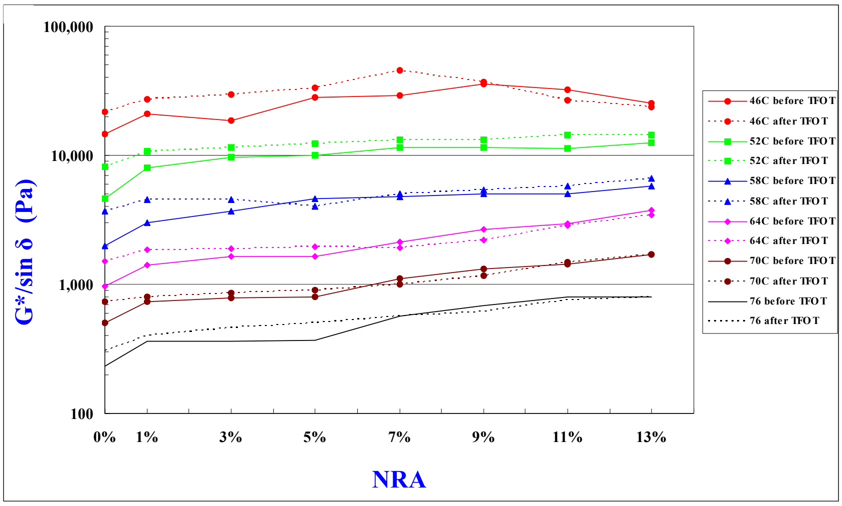


**Figure 6. G*/sin δ Value of Binders at High Temperature**

Figure 6 shows dynamic shear stiffness of binders at high temperature both before and after TFOT. At any temperature, the difference between G*/sin δ before and after TFOT decreased with increasing the content of concentrated latex. It means adding concentrated latex into asphalt cement could reduce aging. G*/sin δ also indicates stiffness of the material, and this value increased by the amount of concentrated latex added. According to SHRP specification, adding more than 7 percent concentrated latex has G*/sin δ exceeds 1.0 kPa. This means that it can use such NRA binders at 70°C while AC 60/70 can be used at maximum temperature of 64°C. Therefore, blending more than 7 percent concentrated latex helps increase stiffness of asphalt cement so that it can be used at higher temperature without permanent deformation. This test result was compatibility trend with softening point test.

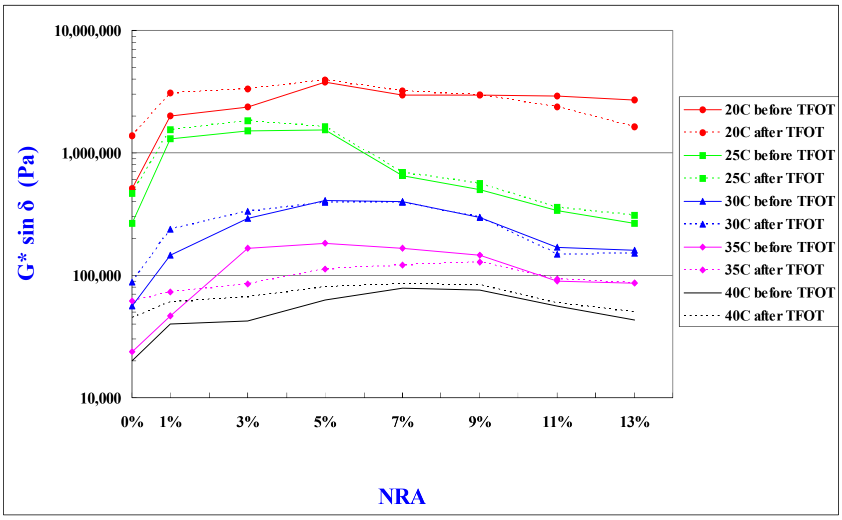


**Figure 7. G*sin δ Value of Binders at Intermediate Temperature**

Figure 7 shows dynamic shear stiffness of binders at intermediate temperature both before and after TFOT. At any temperature, the difference between G*sin δ before and after TFOT decreased by the amount of concentrated latex added. It could reduce aging that it was similar to high temperature test. The G*sin δ value which indicates the stiffness of binders increased and remained steadily at 5-9 percent concentrated latex. After that G*sin δ decreased, especially at 25°C which is the temperature that road surface always damage due to fatigue cracking. It found that G*sin δ suddenly reduced when it mixed more than 5 percent concentrated latex. This indicates that concentrated latex helps increase the stiffness of binders when compared with AC 60/70. In addition, adding more concentrated latex makes the binders not to be too stiff that it could be brittle at intermediate temperature. Although SHRP specification used Pressure Aging Vessel (PAV) to simulate long term aging of binder materials, it needs to be checked the aged binder outcomes in this research by TFOT due to the limitation of lab tools. Thus, it found that all binders could pass the specification by having G*sin δ value not higher than 5.0 MPa.

It can see that it blended concentrated latex into asphalt cement in order to increase G* and decrease δ. It helps provide stiffness and elasticity so the material could reserve traffic and resist permanent deformation at high temperature. At low and intermediate temperature, it prevents the material from cracking due to being too brittle. Furthermore, the low distinction of the test results before and after TFOT indicates the ability to reduce aging.

## 4.2. Asphalt Concrete Mixtures

For the testing properties of asphalt concrete mixtures, the mixtures was compacted by Marshall Method using number of presses according to Heavy traffic criteria to determine the optimum binder content. At 4 percent air void, the properties of asphalt concrete mixtures are shown in Table 4.

**Table 4. Properties of Asphalt Concrete Mixtures by Marshall Method**

| Properties at % Air Void = 4% | Criteria | | 0% | 1% | 3% | 5% | 7% | 9% | 11% | 13% | 15% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min. | Max. | | | | | | | | | |
| % Binder Content | - | | 5.70 | 5.30 | 5.20 | 5.00 | 5.35 | 5.20 | 4.90 | 5.00 | 5.40 |
| Marshall Stability (kN) | 8.00 | - | 8.60 | 9.30 | 9.30 | 10.00 | 10.20 | 10.70 | 11.52 | 13.00 | 14.40 |
| Marshall Flow (0.25 mm. ) | 8 | 14 | 13.70 | 13.60 | 11.80 | 11.00 | 12.00 | 11.50 | 10.50 | 13.00 | 13.50 |
| % VMA | 13 | - | 14.85 | 13.70 | 13.35 | 13.15 | 14.10 | 13.70 | 13.20 | 13.65 | 14.00 |
| % VFA | 65 | 75 | 73.00 | 72.00 | 70.00 | 70.00 | 70.00 | 69.00 | 70.00 | 69.00 | 73.00 |
| Unit Weight (Mg/$m^3$ ) | - | | 2.330 | 2.354 | 2.358 | 2.362 | 2.342 | 2.350 | 2.360 | 2.346 | 2.350 |

The test results of asphalt concrete mixtures by Marshall Method showed that every mixture has value that surpasses all required standards. At 4 percent air void, it found that asphalt concrete that was mixed with NRA binders tends to use less amount of optimum binder content while increasing stability, unit weight and reducing Marshall Flow of asphalt concrete mixtures.

The reason for the decreasing optimum binder content of NRA binders in mixing asphalt concrete was that concentrated latex increased viscosity of asphalt cement, aggregates could absorb less asphalt and was able to be coated with thick film, thereby increasing adhesion among aggregates. Such results could increase stability and reduce rate of stripping. That mixture becomes more durable. Moreover, lower optimum binder content would help reduce maintenance cost due to better road surface. Lower optimum binder content would also reduce total capital for road construction even though it needs to increase some capital for natural rubber

## 4.3. Performance Test

The performance test of asphalt concrete mixtures was performed by compacting samples at optimum binder content from Marshall Method. Figure 8 shows the performance test of asphalt concrete mixtures.

*Indirect Tensile Strength*

Indirect Tensile Strength Test is a test to determine the tension ability of asphalt concrete mixtures by static load. This test also indicates adhesion between aggregates and binders. The test was performed at 25$^{o}$C. The results showed that Indirect Tensile Strength of asphalt concrete mixtures that were mixed with NRA binders tend to increase. The maximum indirect tensile strength occurred at 5 percent concentrated latex and decrease after that point. Beyond 9 percent concentrated latex, indirect tensile strength was lowered than conventional asphalt concrete. This might be that homogeneousness of the mixtures decreases when it applies more percentage of concentrated latex.

*Resilient Modulus*

Resilient modulus was conducted test at four different temperatures by Repeated Load Indirect Tensile Test. Indirect tensile strength until samples failure in previous test was used as referent load for this test. Indirect tensile strengths used were 25 percent, 20 percent, 15 percent, and 10 percent for 15, 25, 35, and 45$^{o}$C test temperatures, respectively. There were two perpendicular alignments load applied on each sample. Resilient Modulus was then measured by averaging the last five values when the test reached at first 150 cycles referred that its value begins constantly (Baburamani, 1992).

At 15 and 25$^{o}$C, asphalt concrete mixed with NRA binders had less resilient modulus than asphalt concrete mixed with AC 60/70 when more than 9 percent concentrated latex was added. This trend indicates that concentrated latex facilitates asphalt concrete mixtures to have less resilient modulus to prevent the materials from being too stiff that it lacks elasticity at low and intermediate temperature. Such lack of elasticity may result in damage due to cracking.

At 35 and 45$^{o}$C, asphalt concrete mixed with NRA binders had more resilient modulus as percentage of concentrated latex increased. The maximum resilient modulus occurred at 13 percent concentrated latex which is 50 percent higher than conventional mix. Thus, it can conclude that asphalt concrete mixed with NRA binders could provide more elasticity to prevent permanent deformation at high temperature.

*Fatigue Property*

Fatigue test was conducted in the same manner as the resilient modulus test. It used Repeated Load Indirect Tensile Test at 25$^{o}$C. Asphalt concrete mixed with NRA binder tend to be able to receive more repeated load according to the content of concentrated latex added. The 13 percent concentrated latex showed approximately four times more in terms of the number of cycles of fatigue life compared with AC 60/70.

*Permanent Deformation*

For permanent deformation test, it will consider number of cycles in receiving repeated load along the axis of samples that generated accumulated strain and deform 1 percent from the height of the samples (Mohamed *et al.*, 1994). In this test, it will be used dynamic creep test at 50$^{o}$C to determine deformation property at 1 percent accumulated stain. When consider the performance properties, asphalt concrete mixtures that were mixed with NRA binders showed potential in extending service life of the road pavement. The number of cycles in resisting repeated load of asphalt concrete mixtures tends to increase with the increasing of concentrated latex content. To compare with asphalt concrete mixtures that were mixed with AC 60/70, asphalt concrete mixtures that had 13 percent concentrated latex added showed better performance approximately four times. This trend is quite similar to the trend from the fatigue test.

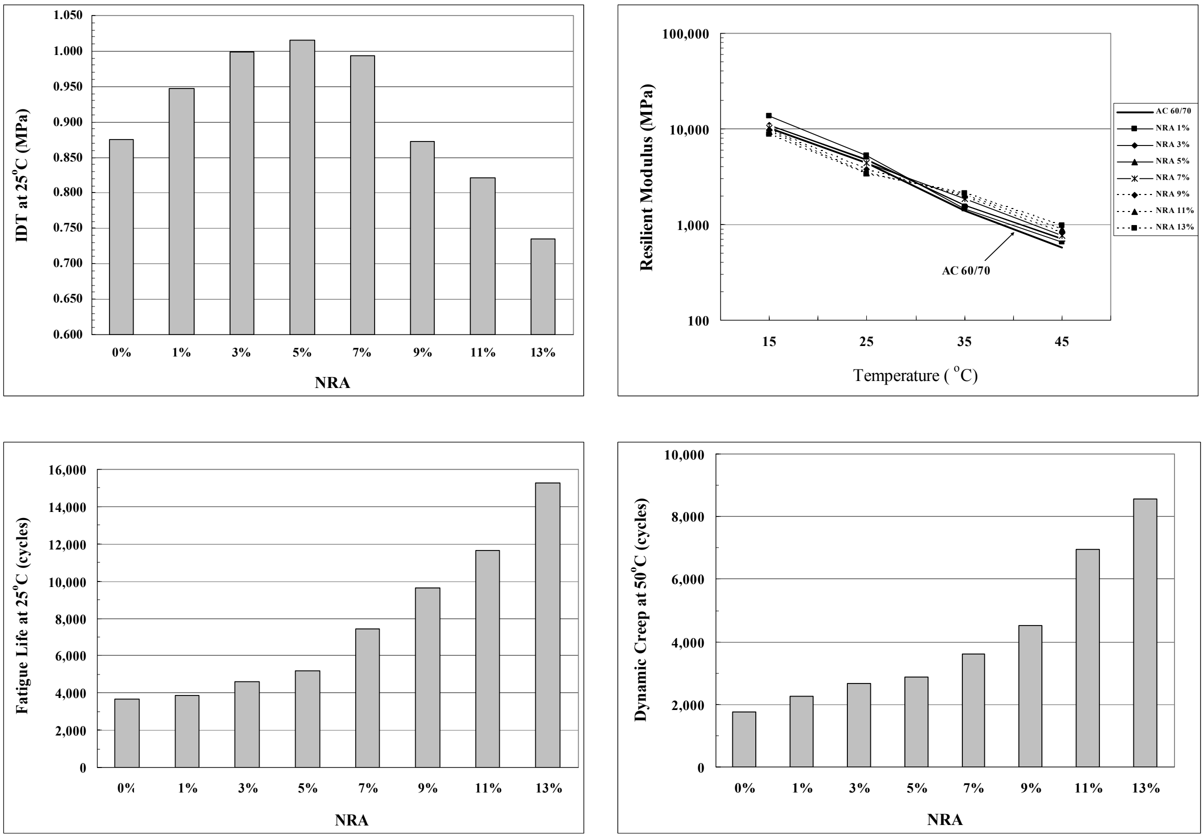


**Figure 8. The Performance Test of Asphalt Concrete Mixtures**

## 5. CONCLUSION

From the study of engineering properties of asphalt cement that mixed with natural rubber in form of concentrated latex in various proportions to be Natural Rubber Asphalt (NRA), these materials will be compared with AC 60/70. It can conclude the results in this research as follows:

### 5.1. Binders

When asphalt cement mixed with concentrated latex at high temperature, particles of natural rubber will swell and will be absorbed by oily constituents of asphalt. Since natural rubber is a polymer compound that has a high molecular weight and it has a lot of complex molecular chain that it was caused polymer chain. These interactions help in the spread of natural rubber into asphalt cement, which make the binders more viscous and more elastic. Changes in properties of asphalt cement are as following:

- An increase in viscosity helps asphalt cement to coat aggregates by thicker film. Such thicker film helps increase cohesion between aggregates that it reduces stripping for the mixtures. In addition, more viscosity helps increase softening point of asphalt cement which then helps reduce deformation, bleeding, and increase road pavement stability at high temperature.
- Concentrated latex could help increase elasticity of asphalt cement at low temperature. In addition, torsional recovery test which is a test for elasticity of asphalt cement showed that NRA binders provided higher percentage of torsional recovery than AC 60/70.
- NRA binders could help reduce aging for asphalt cement according to the amount of concentrated latex added.
- NRA binders could help reduce temperature susceptibility as penetration index (PI) increases by the amount of concentrated latex added.
- An important characteristic when mixing asphalt cement with concentrated latex is that it helps increase elasticity and stiffness of asphalt cement at high temperature to prevent rutting according to the content of concentrated latex added. In addition, it helps asphalt materials flexible enough to prevent the pavement cracking from being stiff at low temperature. From the Dynamic Shear Rheometer (DSR) test, adding concentrated latex made the mixtures work well on service temperature at 70$^{o}$C.

### 5.2. Asphalt Concrete Mixtures

- Asphalt concrete that were mixed with NRA binders could help increase density and stability while such mixtures require less optimum binder content than asphalt concrete mixtures that were mixed with AC 60/70.
- In terms of performance properties, adding concentrated latex help reduce stripping of aggregates in asphalt concrete mixtures and increase resilient modulus at high temperature. Moreover, NRA mixtures also enhance fatigue and permanent deformation resistances better than conventional asphalt cement mixture. It increases service life at least four times when 13 percent concentrated latex was added.

Moreover, it found that the more adding concentrated latex into asphalt cement has effect to the less homogeneity of the binders. The decrease in homogeneity could make some property tests inaccurate, especially at low temperature. Compacting asphalt concrete mixtures is also an important issue since the mixtures have more viscous. The relationship between viscosity and temperature in different proportion of binders that shown in Figure 4 can be used as guideline in mixing and compacting the asphalt concrete mixtures.

From the test results for engineering properties of asphalt cement mixed with concentrated latex or NRA, we found that it is suitable to use natural rubber in form of concentrated latex as additives in asphalt material for roadwork. This is due to superior engineering properties than AC 60/70 in all respects. More importantly, an increase in domestic consumption of natural rubber would prevent the decreasing of natural rubber prices and solve the problem of over capacity of domestic natural rubber in long term.

Although some engineering properties tend to be better by the content of concentrated latex added, it needs to consider some difficulties in preparing mixtures, mixing temperature, mixtures homogeneity, the increased viscosity, and workability. By considering under the laboratory tests for engineering properties of both binders and asphalt concrete mixtures in this research, 9 percent concentrated latex was the suggested appropriate proportion in blending with asphalt cement. Such percentage also showed performance by resisting fatigue and permanent deformation approximately three times better than AC 60/70. Moreover, it requires less optimum binder content than AC 60/70 which may helps in reducing construction capital and long-term maintenance cost for road pavement.

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