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Cleaner Solution Environmental - Natural Rubber Modified Bitumen (NRMB) for sustainable road paving in Thailand

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Abstract

In Thailand, the estimated annual consumption of bitumen in road paving industry and road maintenance for the whole country is about 1 million tons a year. The government spends substantial budget on road maintenance projects every year. Road surfaces are under-going severe traffic loads, especially on the highways where there are high traffic volume and loads. Conventional bitumen has been used throughout the country for road surface with normal traffic volume. However, for the main roads with increased traffic such as highways, the surface will be damaged and fatigued quickly as the ability of conventional bitumen is limited. There is a continual trend to changes in binder usage from conventional bitumen to modified bitumen with five percent natural rubber as is called “Natural Rubber Modified Bitumen” or NRMB. Its direct advantage is to the road users on a better road with enhanced friction, load bearing capacity and durability, which helps reduce an accident. Indirect advantage is to rubber farmers with enhanced volume of rubber usage. It is estimated that 50,000 tons of rubber is used annually in Thailand for bitumen modification. This number substitutes the use of bitumen and promotes the use of natural rubber, which helps rubber farmers in sales volume and stabilized the price. The environmental benefit of the modifications is also perceived in terms of hydrocarbon reduction by using natural rubber, which is biodegradable, to substitute bitumen. The government has also benefited from saving government budgets on longer-term road maintenance due to prolonged life of road. Estimated saving is about 66 billion baht from 2002 to 2012. This paper describes the usages and benefits of natural rubber in asphalt modifications in both hot (NRMB) and cold application (Para Slurry Seal Emulsion) specifically in Thailand road networks.

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1. INTRODUCTION

Thailand is the world's largest Natural Rubber (NR) producer, with 4.47 million tonnes of it having been produced in 2015 alone. The country is responsible for one-third of the world's total output [12]. The processed natural rubber contains 60 percent solid natural rubber. The use of natural rubber in the road paving industry is one of the government campaigns to promote the use of natural rubber in Thailand. It is estimated that 50,000 tonnes of rubber is used annually in Thailand for bitumen modification [13].

There are two forms of natural rubber bitumen usage, which are hot (hot bitumen) and cold (bitumen emulsion) applications. For hot application, natural rubber is introduced to bitumen with five percent solid content by weight of bitumen and this bitumen [7] is called "Natural Rubber Modified Bitumen" or NRMB in Thailand. For cold application, the bitumen emulsion contains 3.5 percent solid content by weight of emulsion [6] and is called "Elastomeric Modified Emulsion" or EMA. The application of this type is called "Para Slurry Seal" or PSS in the Thailand context.

The construction of one traffic lane (3.5m wide) with NRMB and Para Slurry Seal Emulsion uses 1.67 tonnes and 0.98 tonnes of natural rubber per kilometre, respectively. The main advantages of adding natural rubber to bitumen in both hot and cold applications are that the binder has higher softening point and elastic recovery, higher toughness and tenacity and lower penetration. The next sections describe the usages and benefits of natural rubber in bitumen modifications in both hot and cold applications specifically in Thailand road networks.

2. USAGES OF NATURAL RUBBER MODIFIED BITUMEN IN HOT AND COLD APPLICATIONS IN THAILAND

2.1 COLD APPLICATION

Natural rubber can be added into bitumen emulsion for a Para Slurry Seal (PSS) application. The required dosage, according to the Department of Highways (DOH), is at 3.5 percent by weight of bitumen emulsion [6]. This emulsion is a "Quick Set" bitumen emulsion designed for rapid curing time. PSS has prominent features including high-durability, resistance to peeling and resistance to climate changes. It also prevents ingress of water from entering the road surface, promotes skid resistance, and fast curing for opening to traffic quickly within two hours, by Department of Highways (DOH) specification. It is suitable for paving in both residential and high traffic areas.

2.1.1 Material Requirements

There are special requirements for material used for PSS application that will be described in this section. Main components are EMA emulsion, water, Portland Cement (Type 1), additives and aggregates. The aggregates are required to be milled or crushed stone, which has sharp edges, promotes sufficient aggregate angularity and consequently enhance skid resistance to the surface. Mineral Filler typically used in PSS application is Portland Cement. The functions of this filler are to improve workability and aggregates gradation. Additives maybe required to slow down the breaking time. Some aggregate sources that have a high content of fines may require this additive to slow down the breaking time. The aggregates must have good compatibility with the Polymer Modified Emulsion type CSS-1h (EMA), which requires a sand equivalence of ≥ 60%, Los Angeles Abrasion ≤ 35% and Soundness ≤ 9%. Mineral filler, Portland Cement can be used as the filler to mix in as part of aggregates. The required quantity is kept to a minimum as the objective of using Cement is only to increase workability or improve aggregate gradation. Comparisons between Slurry Seal vs Para Slurry Seal are shown in the Table 1, showing both requirements and their applications [3,4].

Table 1. Comparison between Slurry Seal and Para Slurry Seal

Properties	Slurry Seal	Para Slurry Seal
Materials		
Aggregates	Natural Stone	**Crushed stone**
Bitumen Emulsion	CSS-1h	CSS-1h (EMA) or CSS-1hP
Portland Cement	Adjust Flow	Adjust breaking time

Water (Clean)	Control Flow	Control Flow
Additives	Not required	Adjust breaking time (Shell not Required)
Operation		
Traffic Opening	Slow, around 3-4 hrs	**Rapid, around 1 hr**
Performance	Maintain existing pavement and improve drainage	Maintain existing pavement and improve drainage **and improve Skid Resistance**
Paving	Single Layer	**Multiple Layers**

Job Mix Design (JMF) of the slurry is referred to Asphalt Institute Manual Series No.19 and ASTM D3910 "Standard Practice for Design Testing and Construction of Slurry Seal" [2]. The required specifications for slurry tests are shown in Table 2 [4]. The most critical tests for slurry are curing time and Wet Track Abrasion tests. The curing time test is used to identify the time taken for the slurry to harden enough to open the surface to traffic. This parameter is limited to within 2 hours as this type of slurry is designed for minimum traffic opening times. Wet Track Abrasion is designed to check durability of the slurry. Samples of both tests are shown in Figure 1a and 1b, respectively.

Figure 1a. Sample for Curing Time Test, and 1b. Sample for Wet Track Abrasion

Table 2. DOH Specification of Para Slurry Seal

Test	Standards
Mixing Time (min)	120s
Consistency Flow	10-20 mm
Initial Set (max)	30 min.
Cure Time (max)	2 hrs.
Wet Track Abrasion (max)	500 kg/m2
Hubbard Stability@25 degC (min)	11.8 kN

2.1.2 Types of Para Slurry Seal

Para Slurry Seal consists of 3 types, Type 1, Type 2 and Type 3. The main differences are the size of aggregates (shown in Table 3) [4] and emulsion content for slurry seal. The use of Para Slurry Seal is mainly by job specific requirements [9] as follows:

A. Type 1
This is the finest type of all. This slurry has the ability to penetrate cracks. Main application is for crack sealing, surface texture improvements and weathering and oxidation protection

B. Type 2
Type 2 is coarser than Type 1. Main application is for surface maintenance, water drainage and weathering and oxidation protection

C. Type 3
This type is the coarsest. Main application is for improving skid resistance, water drainage, crown slope adjustment and weathering and oxidation protection

Table 3. Types of Para Slurry Seal

Sieve Sizes	Types of PSS		
	Types 1	Types 2	Types 3
	% Passing		
9.5 mm 3/8 inch		100	100
4.75 mm (#4)	100	90-100	70-90
2.36 mm (#8)	90-100	65-90	45-70
1.18 mm (#16)	65-90	45-70	28-50
0.60 mm (#30)	40-65	30-50	19-34
0.300 mm (#50)	25-42	18-30	12-25
0.150 mm (#100)	15-30	10-21	7-18
0.075 mm (#200)	10-20	5-15	5-15
Residual of bitumen by dry weight	10.0-16.0	7.5-13.5	6.5-12.0
Weight per sqm	3.0-5.5	5.5-10.0	10.0-16.0

2.1.3 Equipment

Comparing to typical slurry seal application, there are special equipment that would be required in addition to slurry seal application equipment. These include the spreader box and additive tank shown in the figure below.

Figure 2. Spreader box for PSS application

The spreader box is used to receive slurry from the mixing box, it should be equipped with propellers. These propellers help to mix and spread slurry throughout the box.

Another additional equipment required for this PSS application is the additive tank as shown in Figure 3. This tank is not used for typical slurry seal application. However, this is needed as some of the emulsion may need the additive to slow its breaking time to suit the source of aggregates used in the country.

Figure 3. The additives tank equipped on the slurry truck

Figure 4. Para Slurry Seal as a Surface of Para Slurry Seal

2.1.4 Quality Assurance

There are certain simple field control tests that should be done to ensure the quality of the PSS. Firstly, initial set time should be checked against DOH specification by using a simple field test with a piece of paper (Figure 5). There should be no emulsion sticking to the paper upon breaking (initial set ≤ 30 min.) of the emulsion and the colour should turn from brown to black. Secondly, curing should be checked by using a shoe test (Figure 6). This field test can be done by stepping on the slurry seal by applying body weight on one foot and twist the shoe 90 degree. There should be no facture/crack of slurry upon the completion of curing (cure time ≤ 2hours) [4].

Figure 5. The field test for initial setting time

Figure 6. The shoe test for curing time

2.2 HOT APPLICATION

In Thailand, the first use of Natural Rubber Modified Bitumen (NRMB) on road paving is dated back to 1957, due to the campaign to promote Natural Rubber usage. Natural Rubber (NR) has good elasticity and fatigue resistance [8]. It is introduced in bitumen as a natural polymer that promotes higher softening point, elastic recovery, toughness and tenacity and lower penetration. Natural Asphalt Modified Asphalt (NRMB) has lower temperature susceptibility as a result of higher softening point. Toughness and tenacity are higher resulting in better cohesion.

There was a trial road carried out in Songkha, South of Thailand with the length of 100m (for NRMB Test Section) and another 100 m (AC60/70 in Control Section). The bitumen used in that trial was mixed with 5% Natural Rubber. The trial yielded quite an impressive result that the NRMB test section did not have any major maintenance during the 10-year trial period. However, there was no intense usage of natural rubber in road paving until 2012 [8].

From the cabinet meeting results in 2012, the main agenda for the Ministry of Transportation is to enhance the use of natural rubber in highway networks and railway works including both new built and maintenance projects. The DOH then assigned a team to conduct a feasibility study to use natural rubber in bitumen surface works. They carried out the laboratory study on the properties of AC60/70 with natural rubber addition and the mixture made by NRMB. They also issued the rules and special specifications (Table 4) for mix design and paving of NRMB for a road trial and conducted the site monitoring after construction. From the laboratory study and the site trial results, they found that NRMB has better performance than conventional bitumen but less than Polymer Modified Bitumen. They also suggested that NRMB should be pre-blended from the bitumen supplier and designed to use in the asphalt mixing plant without any modification [5,8].

Key features of NRMB compared to conventional bitumen are shown in Table 4 [5,7]. These include:

a. lower temperature susceptibility as a result of higher softening point
b. Reduced cold flow at low temperature as a result of higher viscosity
c. Increased elastic recovery for better elasticity [11]

Table 4. Direct comparison between conventional AC 60/70 and NRMB

AC60/70 vs NRMB		TEST METHOD	UNIT	AC60/70	NRMB
Items	Binders	TEST METHOD			
1	Penetration @ 25°C	ASTM D5	dmm	60-70	50-70
2	Softening Point, min	ASTM D36	°C	45-55	>50
3	Flash Point, min	ASTM D92	°C	232	220
4	a. Dynamic Viscosity @150 ^{0}C, max (Spindle #21)	ASTM D4402	cP	n/a	200-600
5	Elastic Recovery at 25 ^{0}C, min	ASTM D6084	%	n/a	40
6	Dynamic Shear RTFOT, G*/sinδ at 70 ^{0}C & 10 rad/s, min	AASHTO T315	kPa	n/a	1.0
7	Ductility at 25 ^{0}C, min	ASTM D113	cm	100	n/a
10	Solubility in Trichloroethylene, min	ASTM D42042	%	99	n/a
11	Rubber Content, min	Certificate	%	n/a	5%
Items	Rolling Thin Film Oven Test (RTFOT) Aged	AASHTO T240			
12	Mass Loss, max	AASHTO T240	% wt	0.8	1.0
12	Retained Penetration, min	ASTM D5	%	54	60
13	Variation in Softening Point	ASTM D36	°C	n/a	+6
14	Ductility at 25^{0}C, min	ASTM D113	cm	50	n/a
15	Elastic Recovery at 25 ^{0}C, min	ASTM D6084	%	25	25
Items	After Storage Stability 163 ^{0}C, 24h				
16	Difference in Softening Point, max	ASTM D36	°C	n/a	4

The DOH conducted a site trial in February 2013, on Highway number 305 located in Nakorn Nayok, around 100 km from Bangkok. The trial section was 2 km long and divided into a test section and a control section, which are located consecutively. The DOH ran the site monitoring at 3 months and 6 months by using Falling Weight Deflectometer (FWD), Skid Resistance Tester, Pavement Rutting Tester and Laser Profilometer in order to assess the strength, smoothness, skid resistance and rutting of asphalt. At 85 days after surface opening to the traffic, they conducted the comparison between NRMB and conventional AC and found the followings:

a. Skid Resistance Value (SRV) was improved as the average SRV for NRMB is ≥45
b. Rutting was improved by 32%, load bearing capacity of NRMB is higher as a result
c. Mean Texture Depth (MTD) was improved by 5.7% on the design lane [8]

Shell also conducted laboratory tests, including Marshall Road Performance tests and Hamburg Wheel Tracking tests, to assess and compare road performances between the conventional AC60/70 and NRMB. Marshall Road Performance tests were conducted according to ASTM D6927, Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures. The tests were conducted on both AC60/70 and NRMB wearing course mixtures, with NMAS = 12.5 mm. Marshall volumetric and results are shown in Table 5 below.

Table 5. Marshall Volumetric Summary

Parameters	AC 60/70	NRMB
Binder Content by wt. agg. (%)	5.1	5.1
Aggregate proportions	47:25:15:13	47:25:15:13
Marshall Stability (kN), (Spec.)	16.588, (8.006)	17.577, (9.786)
Marshall Flow (mm), (Spec.)	3.032, (2.000-4.000)	3.505, (2.250-4.250)
Bulk Density (g/cm^3)	2.433	2.485

Marshall results are shown in the table together with the DOH specifications, in the parenthesis. When comparing the values between the two binders, Marshall stability was improved by 5.96% with NRMB.

Hamburg Wheel Tracking Test (HWTT) were conducted per AASHTO T324-19 [1] with the following test parameters:

- HWTT with slab specimens prepared by mixture of the wearing course gradation with NMAS = 12.5 mm
- Specimens submerged in temperature-controlled water at 60°C during testing
- Test conducted with 2 slabs with the thickness of 60 mm
- Tested 20,000 passes by Steel Wheel Rollers
- Air voids; 7.4% for AC60/70 and 7.9% for NRMB

HWTT results are shown in Figure 7 and Table 6. It can be seen from Figure 7 that the maximum impression at failure is 36.40 mm, occurred at 8,500 passes, for AC 60/70. The impression stayed at that level to the end of the test at 20,000 passes where the steel wheels rested on top of the stones. NRMB results, on the other hand, did not fail within 20,000 passes and showed that the impression at 8,500 passes is 27.25 mm. and the impression at 20,000 is 34.24 mm. When comparing the impression at 8,500 passes between the two binders, rut resistance was improved by 33.58% with NRMB. That is also inline with the results from the DOH that rut resistance was improved by 32% mentioned earlier on.

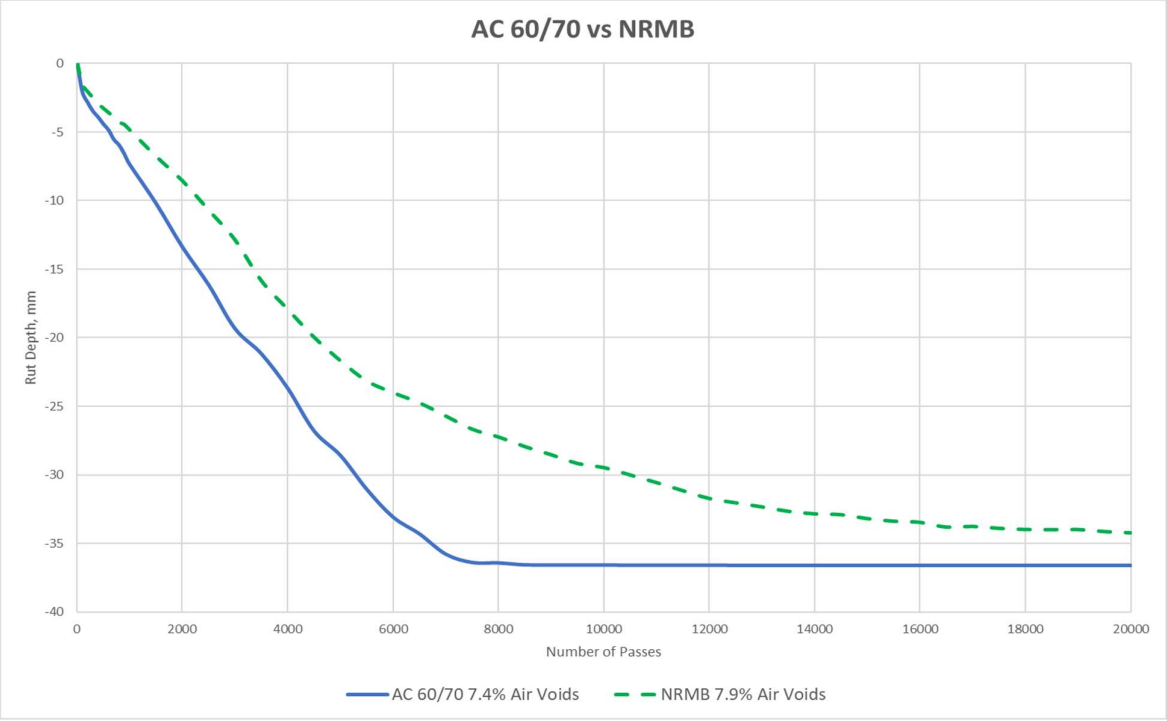

Figure 7. Hamburg Curve with Test Parameters

Table 6. HWTT results comparison between conventional AC 60/70 and NRMB

Parameters	**AC60/70**	**NRMB**
Air Voids (%)	7.4	7.9
Numbers of passes at maximum impression	8,500	20,000
Impression at 8,500 passes (mm)	36.40	27.25
Maximum Impression (mm)	36.40	34.24

Figure 8 showed the specimens after HWTT tests, Figure 8.a) is for AC 60/70 and 8.b) is for NRMB. Each test was conducted on a pair of laboratory fabricated slabs, with the thickness of 60 mm. Specimens were submerged in temperature-controlled water at 60°C during testing. Rut depths were reported as the average value of left and right wheel.

a) **b)**

Figure 8. a) Specimens for AC 60/70, b) Specimens for NRMB

In 2016, The Shell Company of Thailand Limited launched Shell Mexphalte NRMB as to support the government campaign and to support Shell customers for natural rubber road application. Figure 9 shows the paving site conducted with one of Shell contractor in the South of Thailand. Feedback from the customer was good as Mexphalte NRMB is ready to use, easy to apply and easy to compact. The paved road conformed to all the DOH requirements after construction. Shell supplies over 30k tonne of Shell Mexphalte NRMB to Thai customers, annually.

Figure 9. The paving site with Shell Customer in Nakhon Si Thammarat

In 2018, the government campaign to increase the use of natural rubber successfully yielded the results of promoting the use of 22,262.37 tons of natural rubber, which is equivalent to 13,330 kilometers of road paved. Providing that the construction of one traffic lane (3.5m) with NRMB uses 1.67 tonne of natural rubber per kilometer [10].

2.3 CONCLUSION

Natural Rubber (NR) can be added into bitumen and used in both cold and hot applications. For cold application, EMA is successfully used for Para Slurry Seal as a rapid surface treatment in Thailand. Main advantage of this application includes quick traffic opening, within two hours after paving. Ride quality and road safety are also improved as the surface texture is higher due to bigger aggregate size used.

For hot applications, NRMB asphalt has improved rut resistance, higher skid resistance and higher mean texture depth. The mixture also yielded higher Marshall Stability due to higher stiffness, resulting in more durable and higher load bearing capacity to the road.

The engineering benefits of natural rubber in bitumen are clearly demonstrated in this paper. There are also the economic benefits to the country as there is a significant volume of natural rubber used on road paving in Thailand to improve durability of the pavements, substituting the use of bitumen and promoting the use of natural rubber in terms of hydrocarbon reduction as the natural rubber is biodegradable.

3 REFERENCES

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