Effects of crumbed para rubber on permanent deformation resistance of hot mix asphalt

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Abstract. In Thailand, natural para rubber (Hevea Brasiliensis) is gaining application in asphalt pavement construction. The natural rubber element helps extending the life period of asphalt pavement. Currently para rubber in a latex form is slowly added to hot asphalt binder and mixed together using shear mixer. An alternative of adding para rubber into asphalt pavement is applying para rubber crumbs into the hot mix asphalt (HMA) during the batch mixing process which is 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 resilient modulus and dynamic creep responses. The results showed that adding crumbed para rubber in aggregate by dispersive mixing method is the most effective method. It has increased significantly the resistance to permanent deformation compared with the conventional mixture.

1. Introduction
South East Asia has long been the major production source of para rubber. In the last ten years, Thailand has produced more than 3 million tons per year and around 90 percent has been exported to other countries [1]. But the global consumption of para rubber has decreased for the past five years. Thai government has stimulated the local consumption of para rubber by introducing para rubber latex into modified asphalt cement production for pavement construction projects throughout its national highways. In facts, there were many research works showing para rubber modified asphalt performed better than the ordinary asphalt [2, 3, 4, 5, 6, 7].

Technically, para rubber can be blended into HMA by two different ways, “wet process” and “dry process”. In the wet process, para rubber latex is mixed into asphalt cement at high temperature and the product is named natural rubber modified asphalt (NRMA). NRMA contains para rubber content at 5% – 12% by weight of asphalt cement. At present, only the wet process is 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, it 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 adding into NRMA of which controls the unit price of NRMA.

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

- Quantity of crumbled para rubber in asphalt concrete can be measured and monitored during construction;
- No need for special transportation;
- 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 [8, 9].

In dry process, para rubber makes contact to asphalt cement at high temperature for only few hours, para rubber is not fully melted and fused into asphalt cement body [10]. This method is often considered less efficient of using modifier than the wet process. However, there were past research works [8, 9] indicated that the dry process allowed for higher rubber content than the wet process and could result in a similar output of modification. The objectives of this study were to investigate the performance of the HMA modified with crumbled para rubber in relative to the conventional HMA and the HMA with NRMA within a scope of rutting resistant which is the major damage concern of wearing course in Thailand.

2. Research methodology

2.1 Materials

The following ingredients were used in producing HMA specimens in this study:

- Limestone aggregate with the basic properties according to the Marshall Mix Design specification of Department of Highways (DOH) for asphalt concrete wearing course for 12.5-millimeter nominal size of aggregate. The aggregate gradation was fine and dense-graded.
- Asphalt cement penetration grade 60/70 (AC 60/70). The optimum binder content based on Marshall mix design to produce 4% air voids was 5.4 % by total mixture weight. This binder content was then used for all specimens.
- Crumbled para rubber particles with the size of 2.36 – 4.75 mm i.e. passing # 4 sieve and retaining on #8 sieve. It was used for producing the specimens in the dry process. Based on the previous study [8], the crumbled para rubber of 2 percent by volume of total mixture (or 0.8% of total asphalt mixture weight) was selected. The same amount of 2.36-4.75mm aggregate was replaced by the crumbled para rubber to maintain the particle size distribution. Crumbled para rubber particles were pre-coated lightly with hot asphalt cement using rubber:asphalt weight ratio of 6:1 and lightly powdered with rock dust.
- NRMA containing para rubber substance 7 % of asphalt cement weight conformed to the DOH specification for producing the specimens in the wet process.

2.2 Specimen preparation methods

In the conventional HMA specimen preparation, 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 [11].

For HMA specimens with crumbled para rubber, this research considered two adding methods for the dry process: dispersive mixing method and layer placing method.

- Dispersive mixing method. This method simulated adding para rubber into the pug mill of a hot mixing plant. In laboratory, HMA ingredients were mixed thoroughly at the mixing temperature 160 ºC before adding crumbled para rubber particles into the mixer to allow the
crumbed particles dispersed thoroughly. They were mixed until all crumbed para rubber particles were well coated with asphalt cement.

- **Layer placing method.** The idea of this method was to add para rubber at road site by spreading crumbled para rubber on tag coat before paving an asphalt concrete overlay. In laboratory, it began with preparing HMA in a mixer at 160 °C. Then the mixture was split into two equal portions. The first portion was charged into a cylindrical mold and lightly tamped. After that the weighed amount of crumbled para rubber particles were spread on top of the first HMA portion. The second HMA portion was then charged into the mold. Lastly the mold was brought to compaction. By this way, crumbled para rubber was placed between bottom and top layers of HMA at compacting temperature, i.e. crumbled para rubber layer was sandwiched between HMA.

![Figure 1](image1.png)

**Figure 1.** Dispersive mixing method (left) and layer placing method (right).

### 2.3 Experimental design

Four treatment cases of specimens were studied:

- **Conventional HMA:** 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.

#### Table 1. Hot mix asphalt specimen testing details

| Description                                                                 | specimens | Test standard       |
|----------------------------------------------------------------------------|-----------|---------------------|
| 1 Indirect tensile strength test (IDT)                                     | 3         | ASTM D6931-12 [12]  |
| - Constant rate of loading 50 mm/min, at 25°C                              |           |                     |
| 2 Indirect tension test for resilient modulus of bituminous mixtures      | 3         | ASTM D4123-82 [13]  |
| - applying repeated 1Hz havesine pulse loading frequency (0.1 second loading period, 0.9 second rest period) at 25, 37.5 and 50°C, at repetitions loading 100 value and 10 percent of IDT. |           |                     |
3 Dynamic creep test
- using repeated 0.5 Hz square pulse loading frequency
  (0.5 second loading period, 1.5 second rest period), at
  50°C temperature, stress level=200kpa, at accumulated
  strain=3%

2.4 Testing methods
All specimens were compacted by gyratory compactor to achieve 5 percent air voids with specimen
height of 50 mm. First, indirect tensile strength tests [12] were conducted on specimens of the four
treatment cases. After that, resilient modulus tests were conducted at three different temperatures 25,
37.5 and 50 ºC. The loading magnitude was chosen based on 10 percent of indirect tensile strength
according to the test standard [13]. The resilient modulus result of each specimen was determined based
on averaging the final five cycles when this test was finished to 100 cycles [13].

For rutting resistance evaluation, Australian Standard procedure of dynamic creep test was used.
The cyclic 200 kPa vertical loads of trapezoidal shape were applied to the specimen repeatedly until
20,000 cycles or the permanent vertical strain exceeds 30,000 microstrains. The test was conducted at
50°C to simulate the accelerating condition [14]. These specimens were tested according to the
performance tests listed in Table 1.

3. Results analysis and discussion

3.1 Indirect tensile strength
From figure 2, the results showed that all dry process treatment cases had resulted in higher indirect
tensile strength than the conventional HMA. The case of dispersive mixing method provided the highest
indirect tensile strength, the layer placing method was the second. The wet process case had about the
same indirect tensile strength as the conventional HMA case.

![Figure 2. Average indirect tensile strength of the four cases.](image)

![Figure 3. Average resilient modulus of the four cases at three temperature levels.](image)

3.2 Resilient modulus
The results of resilient modulus at three temperatures are shown in Figure 3.

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.
3.3 Resistance to permanent deformation

The creep strain data of each specimen was plotted in figure 4. The minimum slope of creep strain and the cycle at minimum slope were calculated from the permanent strain record during the test. The graphs of accumulated strain behavior under the repeated loading cycles revealed the resistance of the mixture to the permanent deformation. According to the test standard, the lower slope value means the better resistance to permanent deformation in the field [14, 15].

![Accumulated Strains vs Cycles](image)

**Figure 4.** Results of strain accumulation in dynamic creep tests (L=layer placing method, D=dispersive method, W=wet process, H=conventional HMA).

| Method                        | Specimen | Min slope (με/cycle) | Cycle @min slope |
|-------------------------------|----------|----------------------|------------------|
| Layer placing method          | L-1      | 1.5                  | 5000             |
|                               | L-2      | 0.5                  | 10000            |
|                               | L-3      | 0.2                  | 20000            |
|                               | L-4      | 1.8                  | 3400             |
|                               | L-5      | 1.2                  | 5000             |
| Dispersive mixing method      | D-1      | 0.8                  | 7200             |
|                               | D-2      | 0.3                  | 14400            |
|                               | D-3      | 0.3                  | 16800            |
|                               | D-4      | 1.0                  | 7200             |
|                               | D-5      | 1.5                  | 5000             |
| Wet process                   | W-1      | 0.6                  | 10000            |
|                               | W-2      | 0.3                  | 18800            |
|                               | W-3      | 1.4                  | 5000             |
|                               | W-4      | 1.3                  | 4000             |
|                               | W-5      | 0.3                  | 7500             |
| Conventional HMA              | H-1      | 1.6                  | 3100             |

**Table 2.** Analysis results of dynamic creep tests
The analysis of minimum slope revealed the results presented in table 2. The average values of minimum slope results were shown in figure 5. The results in figure 4 showed that HMA modified by the three treatment cases as dispersive mixing method, layer placing method and wet process had significantly lower cumulative strains than the conventional HMA specimens. In table 2, the specimens of three modified cases had the minimum slope significantly lower than the conventional HMA. In ranking cases based on the average minimum creep slope shown in figure 5, the dispersive mixing method and the wet process were the best, the layer placing method was the second and the conventional HMA was the last. Furthermore, all of the modified treatment cases were able to extend the testing cycles much longer than the conventional HMA.

4. Conclusion and recommendation

This research has investigated the potential of using para rubber with dry mixing process to improve structural properties of HMA. From the test results, it seems that both crumbed para rubber with dispersive mixing method and the NRMA wet process perform the best of the group in increasing the engineering properties of HMA 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 HMA 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.
Furthermore, a study on price comparison between the dispersive mixing method and the wet process in construction is recommended to know the different price between the wet process and dry process.

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