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Article

Influences of Particle Size and Content on Deformation Resistance of Crumb Rubber Modified Asphalt using Dry Process Mix

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Abstract. Crumb Rubber Modified (CRM) is one of techniques for improving asphalt mixture performance. There are two alternatives for applying crumb rubber (CR) to Hot Mix Asphalt (HMA), “Wet” and “Dry”. In the wet process, CR is added into hot asphalt cement in a factory, then CR-asphalt cement infusion is transported to a HMA plant for blending with hot aggregates. In the Dry process, CR is blended with hot aggregates and asphalt cement directly in a HMA plant. Although the dry process is considered less efficient due to lower infusion with asphalt cement, it offers some advantages that CR content can be independently controlled and higher amount of CR can be added into the HMA. This study focuses on dry process that uses CR modification by replacing some aggregate particles in mixture. HMA is blended with CR in 3 different sizes: 1.18-2.36mm, 0.6-1.18mm and smaller than 0.6mm. The x-sized CR is added to the mixture in substitution of the same x-sized aggregate particles at the amount of 1% and 2% by the whole aggregate volume in the mixture. The mixtures’ performance in deformation resistance is represented by Wheel Tracking Slope (WTS). The results of Wheel Tracking tests on the specimens are enlightening. The mixture with CR particles smaller than 0.6mm shows excellent performance on deformation resistance, indicated by significantly lower WTS than others. Secondly, mixtures with higher amounts of CR have better performance than those with lower amounts. The mixture with 2% CR with smaller than 0.6mm provides optimal performance at 2.1 times better than conventional HMA.

Keywords: Crumb rubber modified asphalt, hot mix asphalt, permanent deformation, rutting.

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1. Introduction

The number of vehicles on road networks continues to increase rapidly over time; this is especially true for trucks, whose registrations have currently risen to well over one million [1]. Expected future increases in traffic volume will result in greater cumulative vehicle loads and accelerated damages to road structure, particularly rutting damage, which is the most common type of damage for road networks in Thailand [2]. Rutting is a severe form of road damage that has significant impact on road safety. A 0.5-inch (13-mm) rut depth will cause a Present Serviceability Index (PSI) loss of 0.35; at this depth, road safety begins to be affected [3].

Furthermore, the increasing number of vehicles also leads to more waste tire rubber that needs to be suitably disposed of to prevent negative impact on to the environment. An effective technique for waste tire rubber disposal is that of shredding and grinding it into scrap rubber of various sizes for subsequent processing and utilization. Crumb Rubber Modified (CRM) is another popular technology for the improvement of HMA performance that has been developed and widely used over the past 30 years. Improved properties of CRM-HMA include increased tensile strength at high temperature, and increased material resilience at moderate temperature, as well as less fatigue and thermal cracking of mix materials [4]. Many test results have also confirmed that pavement structure built with CRM-HMA is notably more efficient for various field applications than conventional HMA [5, 6, 7]. Despite its higher cost and the need for more complex construction techniques [8] the use of CRM-HMA can be rewarding due to the many benefits derived from its improved engineering properties. CRM-HMA can provide longer road service life with lower maintenance costs [9].

Technologies for the improvement of CRM-HMA quality can be divided into two main types: the wet and dry processes. In the wet process, small CR particles of suitable size and quantity are added to asphalt cement and blended with other aggregates to produce paving HMA. The process requires a specialized blending unit for the blending of CR particles and asphalt cement, which is equipped with fans for a thorough dispersal of CR particles into the asphalt cement. The resulting CRM-asphalt cement is then sent to a reaction device, which is a container that can be heated, and which is equipped with a set of small stirrers to prevent separation of rubber crumb particles from asphalt cement during the reaction process [5].

In the dry process, CR particles of suitable size and quantity are added to HMA as a replacement for a specific-sized aggregate, or as the mixture additive. CR particles are directly blended into HMA during the hot mix asphalt production process. However, the dry process can be used with HMA only [6]. The process is outstanding for its expedient manufacturing process and absence of requirement for a modification to the existing production system. It can be used with both batch and drum production processes. The dry process technique for adding CR particles during a production process is the same as the technique for adding other aggregates [7]. However, asphalt mixtures that are produced using this technique indicate the higher amount of Optimum Binder Content than that which is produced conventionally [10].

Several overseas studies have found the wearing course structure built with dry process CRM-HMA to have inferior performance efficiency and fewer field applications than wet process CRM-HMA [11, 18]. However, the dry process is more convenient to produce industrially as its production process is not much different from the conventional production process, with less extra work required during the paving process [6, 7, 12]. Therefore, the dry process should be more suitable for Thailand, where relevant knowledge and suitable equipment for the wet process are not adequately available.

Although dry process CRM-HMA is inferior to wet process CRM-HMA in terms of performance efficiency, its resistance to permanent rutting is superior to that of conventional HMA. This fact has been confirmed by a combination of many overseas research findings, laboratory test results [13, 14, 15, 16] and field experiments monitoring outcomes [12, 17]. Table 1 presents a summary of comparison between Dry Process and Wet Process.

The above-mentioned strengths of dry process technology for the improvement of HMA make it suitable for the construction conditions of Thailand, where a wet process plant is not yet available. Dry process CRM-HMA requires no special care in its transportation, site storage and pipeline transportation. This study mainly focuses on the use of dry process technology to improve the performance efficiency of HMA that complies with the material properties and HMA mixture design technique requirements prescribed by Thailand's Department of Highways (DOH).

Table 1. Comparison of crumb rubber modification between "Dry Process" and "Wet Process".

<table>
<tr><th>Subject</th><th>Dry Process</th><th>Wet Process</th></tr>
<tr><td>Brief Description</td><td>A method of adding crumb rubber directly into asphalt mixture during mixing process [19]. Added crumb rubber is used as rubber aggregate in mixture [20].</td><td>A Production of modified binder by blended fine particle crumb rubber with asphalt binder by specific machine [19]. After considered digestion period, binder properties are improved and is added to the mixture [15].</td></tr>
<tr><td>Crumb Rubber Content and Size</td><td>• Crumb Rubber is added to substitute aggregate in mixture for 1-3% [20].
• Wide range in size of crumb rubber is used. From coarse particle (sieve size 6.3 to 2.36 mm) to ultrafine (sieve size 0.180 mm) [20].
• The usage of crumb rubber is higher than wet process for 2 – 4 times [4].
• In the New Generic Dry System, #16 to #80 ground CRM of less than 1.5% by weight of mix was added strictly to dense-graded asphalt mixture [11].
• Hernandez-Olivares et al. [12] studied on CRM asphalt concrete using dry process by applying CR size smaller than 1.0mm at 1% by aggregate weight in the dense-graded HMA.</td><td>• At least 15% of crumb rubber by binder weight is used in modification process of binder, 18% - 22% is recommended [20].
• Typical maximum size of crumb rubber is 2 mm. However, particle finer than sieve size 0.300 mm is recommended [20].</td></tr>
<tr><td>Complication in production process</td><td>• No special equipment is necessary, since mixture production until road construction [19].
• Using typical protocol in Asphalt mixture production. Crumb rubber is blended with aggregates before the addition of unmodified binder [12].</td><td>• In modified asphalt binder production, specific blending machine is required [19].
• For a completed reaction, at least 175 °C in blending chamber, and 45 minutes of blending time [5].
• Many tests for engineering properties of binder are conducted, for meet a requirement of modified binder [20].
• In asphalt mixture production, required specific tanker and sufficient storage area [19].</td></tr>
<tr><td rowspan="2">Engineering Performance of Modified asphalt concrete</td><td colspan="2">• Crumb rubber modified asphalt, both wet and dry process, show a better performance than conventional asphalt mixture [14].</td></tr>
<tr><td>• According to rigidity and shape of rubber, rubber particle could absorb stress from traffic load [5]. Pavement distresses which related to fatigue and plastic deformation would be reduced [15].
• Dry process asphalt mixture shows less performance (moisture susceptibility, aggregate detachment and pavement bearing capacity) comparing to wet process because of a less homogeneous of rubber particle than wet process [15].</td><td>• Performance in term of prevention of Cracking, Rutting, Aging is improved. Due to higher viscosity modified binder and chemical reaction by crumb rubber [5].</td></tr>
</table>

2. Scope of Study

The objective of this study aims to examine changes in the resistance to permanent rutting of dry process CRM-HMA with the intention of using CR particles as an aggregate in HMA. It is, therefore, necessary for the study to have control over the quantity of aggregates, which need to be uniform in both the modified and non-modified HMAs. In this study, two factors related to rubber aggregate in the HMAs were emphasized: its size and quantity.

The HMA mixture design and material properties in this study were in accordance with the DOH requirements for dense-graded HMA [21]. A Wheel Tracking test, the European standard test method for the resistance to permanent rutting property of HMA, was used [22].

3. Research Procedures

3.1. HMA Mixture Design

The aggregate used in the HMA mixture design of this study was limestone from a quarry in Suphanburi Province. The asphalt cement was Pen 60-70 grade asphalt. The material properties of both components were in accordance with the DOH requirement.

Based on the DOH requirement for HMA mix design, the Marshall mix design method was adopted in the design of binder-course HMA for high traffic volume support (High Traffic: ESAL > 10^6 ESALs). The mixture gradation was dense-graded on coarse side with nominal maximum aggregate size of 19.0 mm (3/4 inches). Details of the aggregate gradation of the HMA used in the study is shown in Table 2 and Fig. 1.

In the HMA mix design, the optimum binder content (OBC) was selected based on 4% air voids (AV) criteria. The results of Marshall mix design of the prototype mixtures in this study is shown in Table 3.

Table 2. Selected gradation and bulk specific gravity of aggregate in this study.

Sieve Size	Opening in mm	Bulk Specific Gravity (Gsb)	% Passing by weight of aggregate	% Retained on sieve	
				by weight of aggregate	by volume of aggregate
1 inch	25.0	2.704	100.0	4.6	4.6
3/4 inch	19.0	2.710	95.4	25.0	24.9
1/2 inch	12.5	2.707	70.4	13.5	13.4
3/8 inch	9.5	2.712	56.9	18.9	18.7
#4	4.75	2.720	38.0	13.7	13.6
#8	2.36	2.678	24.3	7.0	7.1
#16	1.18	2.630	17.2	5.2	5.4
#30	0.600	2.606	12.0	4.0	4.1
#50	0.300	2.636	8.0	2.5	2.6
#100	0.150	2.692	5.5	1.5	1.5
#200	0.075	2.631	4.0	4.0	4.1
pan			0	0	0
Sum				100.0	100

Table 3. Summary of volumetric properties for selected HMA.

Optimum binder content determination				
%Asphalt Cement @ max Gmb	5.9%	Optimum Binder Content (OBC)		5.4%
% Asphalt Cement @ max stability	4.9%			
% Asphalt Cement @ middle AV limit	5.4%			
Requirement for heavy traffic level according to DOH recommendation				
Requirements	value	minimum criteria	maximum criteria	testing result
%AV @ OBC (%)	4	3	5	passed
stability @ OBC (kN)	12.2	8	-	passed
flow @ OBC (0.25 mm)	13.5	8	14	passed
VMA @ OBC (%)	14.7	14	-	passed

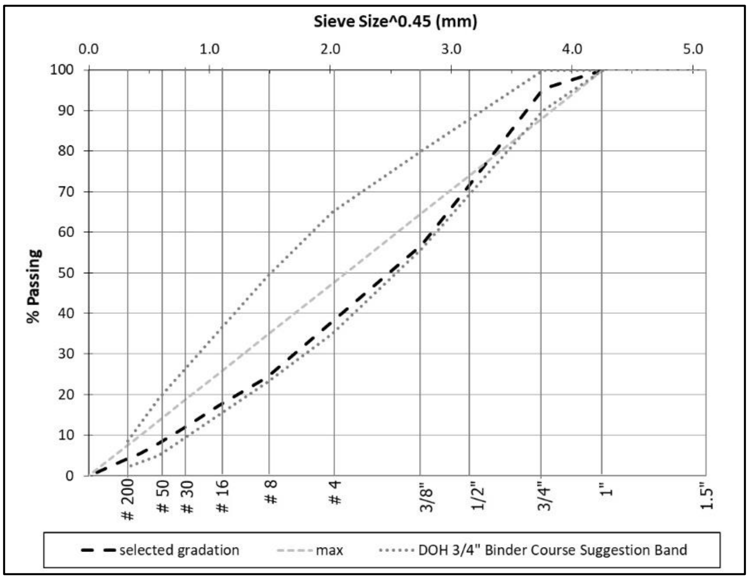

Fig. 1. Gradation graph representing aggregate particle distribution and the DOH suggested band.

3.2. Crumb Rubber Particles Size and Content Selection

The CR particles used in this study were shredded recycled truck tires from a tire recycling factory in Thailand. The specific gravity of the selected CR was 1.105. Most crumb rubber factories in Thailand produced large volume of CR in a range from powder size to 2.0 mm approximately. In this study, CR particles of three sizes were selected for substituting in some portion of limestone fine aggregate in the HMA. The selected sizes were:

- o P#8R#16: CR particles passing #8 sieve and retained on #16 sieve with size between 1.18 – 2.36 mm for representing large-sized fine aggregates.
- o P#16R#30: CR particles passing #16 sieve and retained on #30 sieve with size between 0.6 – 1.18 mm for representing medium-sized fine aggregates.
- o P#30: CR particles passing #30 sieve with size smaller than 0.6 mm for representing small-sized fine aggregates.

The selected sizes were in the same range used in some related studies [11, 12, 20] as shown in Table 1. Another reason on selecting fine aggregate sizes was because during the early stage of this study, many CR cases were tested for dry process mixing with HMA. They included a range of CR particle sizes from smaller than 0.6 mm up to 9 mm and a range of CR content up to 8% by total aggregate volume. On cases of CR content higher than 2% or CR particle size larger than 2.36mm, it appeared that the specimen surface could not remain in the required shape after completion of compaction process. It probably happened due to the fact that they contained high total CR volume which were under high compressive deformation during compaction process. After compaction finished, the CR particles tried to rebound to their original uncompressed volume before compaction. As such, the specimens could not remain in the desired shape.

Adding CR to the asphalt cement-aggregate mixture was considered to avoid disturbing the existing gradation structure of aggregate. The idea was to add CR particles as part of an HMA mixture to function as elastic aggregate particles. The added CR particles became part of the HMA mixture, while the mixture's overall aggregate size distribution remained the same. This was designed to control any change in the mixture's volumetric characteristic upon the addition of CR particles. This was done by taking out the same volume of limestone aggregate as a specific volume of CR particles was introduced to the mixture. In other words, the sum of volume of the CR particles and remaining limestone aggregate in the mixture would be the same as the volume of limestone aggregate in the original Marshall mix design result (Table 2).

This study controlled the volume of CR particles to be added to the mixture. On CR content selection, two portions of CR particles to be added to HMA were 1% and 2% by total volume of aggregate. A summary of trial parameters and levels in this study is shown in Table 4.

3.3. CR-HMA Blending Method

Two methods of adding CR particles to the HMA were originally considered in this research, in accordance with the industrial practice of HMA production and the field practice of HMA pavement construction.

- CR particles were added and blended with other aggregate during the hot aggregate and hot asphalt cement blending step to simulate the blending process performed in the pug mill of an HMA plant.
- CR particles were added to ready-mixed HMA and were thoroughly mixed before being compacted to simulate the adding of CR particles to the hopper of a paver in the construction site. The mixture was immediately crushed by a compactor.

During the pilot mixing and compacting processes of the second method, it was found that the compacted specimen could not remain in a good shape for further testing. An example shown in Fig. 2 for a cylindrical shaped specimen, the specimen could not remain vertical after being released from the mould and left for some minutes. Therefore, adding CR particles to hot aggregate-asphalt mixture during the blending step of production was applied to all specimens.

Table 4. Scope for experimental study in producing CRM specimens in this study.

Factor	Description	Different Level
1. Size of crumb rubber	• P#8R#16 (1.18 – 2.36 mm) • P#16R#30 (0.6 – 1.18 mm) • P#30 (<0.6 mm)	3
2. Quantity of crumb rubber	• 1% by total volume of aggregate • 2% by total volume of aggregate	2
Total treatment for experimental (including base condition) 3 x 2 + 1 =7		

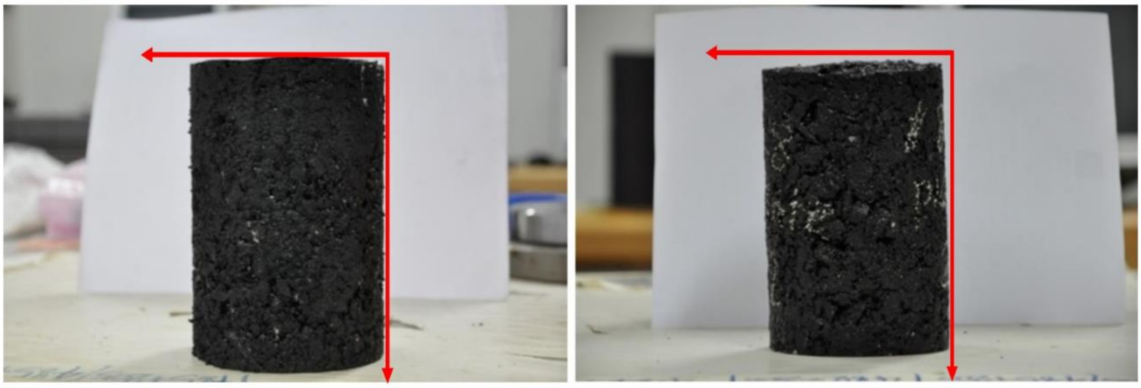

Fig. 2. Compacted sample from mixture with CR added during mixing process (left), CR added during compaction process (right).

3.4. Wheel Tracking Test for Resistance to Permanent Deformation

The Wheel Tracking test is a testing method that is widely used for evaluating the resistance to permanent deformation of HMA materials as it provides good correlation between laboratory test results and the actual field deformation of paving materials [23]. In the test, repeated forces are applied to the surface of plate-shaped HMA specimen by running a loaded wheel over the specimen. The wheel is weighted to produce sufficient pressure to the specimen plate for deformation to develop in the form of ruts. The

HMA plate can be prepared in a laboratory or collected from the field. The BS EN 12697-22 [22] Wheel Tracking with a small size device (Model B in air) test procedure was used in this study. This device is shown in Fig. 3. According to the test standard, minimum of two specimens were required for testing. The averaged test result was then used to represent the two specimens.

Two specimen plates per one experimental case of experimental design in Table 4 were prepared in the laboratory using the roller compactor in accordance with the BS EN 12697-33:2003 standard [24]. Figure 4 shows this compacting machine. The specimen plate preparation involved blending and compacting of HMA into 30.5 cm x 30.5 cm rectangular plates of 5 cm thickness with 7% air void in the mixture which was 3% higher than the HMA mixture design condition (4%AV) to represent the field condition of newly laid HMA layer construction [25, 26].

Fig. 3. Wheel tracking tester machine.

Fig. 4. Roller compactor machine.

Upon completion of the specimen preparation, the Wheel Tracking test was conducted under following conditions during the test.

- Temperature in testing chamber controlled at 50 °C
- Acting force from smooth steel with rubber coated wheel to surface's specimen is 700 N
- Wheel passing speed controlled at 26.5 revolutions/minute
- Test terminated at 10,000-load cycles (Equivalent to 20,000-wheel passes)

According to the testing standard [22], the Wheel Tracking Slope (WTS) values can be calculated using Eq. (1) for each specimen plate. A typical figure of specimen after 10,000-wheel load cycles shown in Fig. 5, a rut occurred along wheel path at a middle of slab. A typical relationship between rut depth and load cycles which described the definition of WTS shown in Fig. 6.

$$\mathrm{WTS} = \frac{D_{10,000} - D_{5,000}}{5} \tag{1}$$

Where, WTS = Wheel Tracking Slope in mm / 1,000 load cycles
$D_{10,000}$ = Rut depth at wheel path at 10,000 load cycles
$D_{5,000}$ = Rut depth at wheel path at 5,000 load cycles

An HMA specimen with low WTS value indicates good resistance to permanent deformation. This means mixtures with low WTS values requires more test cycle time than mixtures with high WTS values to create the same rut depth.

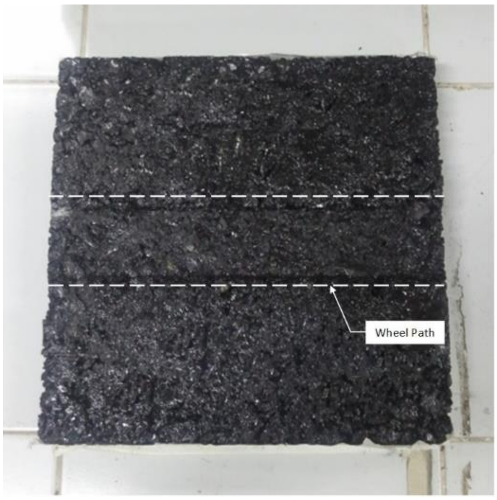

Fig. 4. Specimen after wheel track test termination.

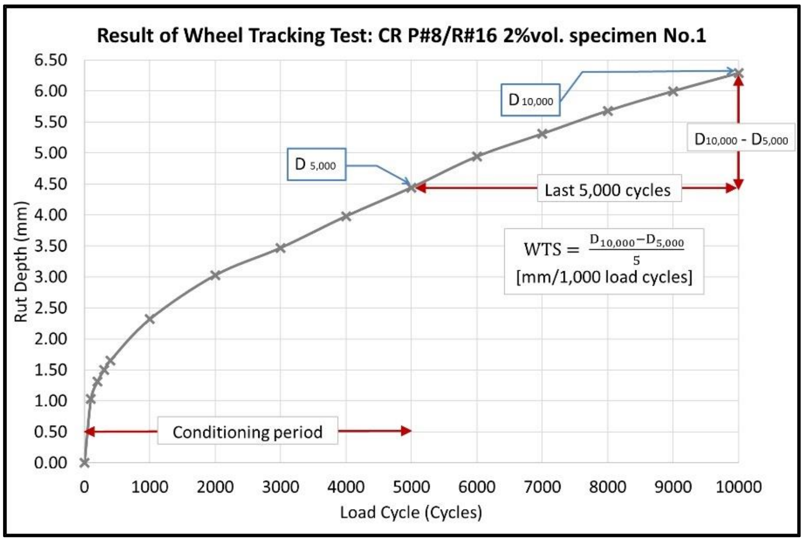

Fig. 5. Wheel tracking test result and WTS description of specimen no.1 with CR particles size P#8R#16 2% by aggregate volume.

4. Analysis of Results and Discussion

Test results from Wheel Tracking Test which relate to the permanent deformation resistance of asphalt mixture are shown in this section. The relationship between rut depth and wheel passing cycles from each specimen from whole treatments are plotted in Fig. 7, and the test results are summarized in Table 5.

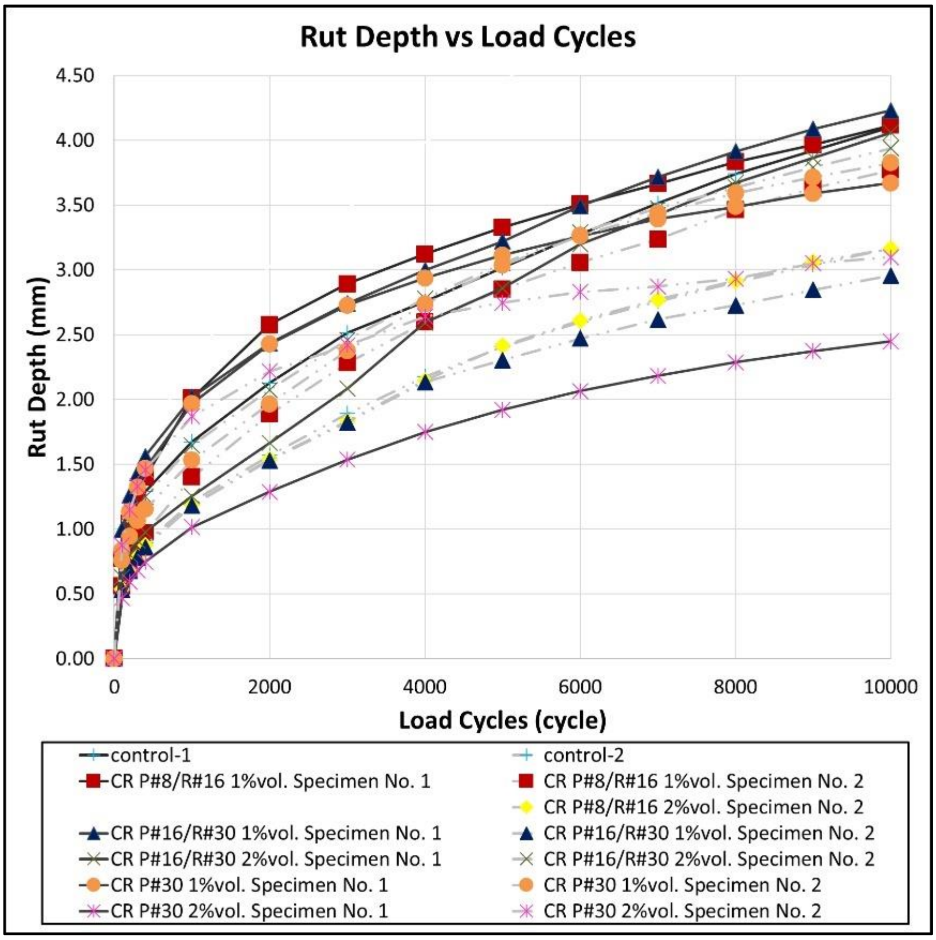

Fig. 7. Relationship between rut depth and wheel passing cycles, whole treatment results.

Table 5. Wheel tracking test results from whole treatments.

Treatments	Rut depth (RD) after test termination (mm)			WTS (mm/1000 load cycles)		
	Specimen-1	Specimen-2	Average	Specimen-1	Speciemen-2	Average
control	4.10	3.17	3.63	0.22	0.15	0.19
P#8R#16-1%vol	4.12	3.77	3.94	0.16	0.18	0.17
P#8R#16-2%vol	6.29	3.16	4.73	0.37	0.15	0.26
P#16R#30-1%vol	4.23	2.96	3.59	0.20	0.13	0.17
P#16R #30-2%vol	4.06	3.94	4.00	0.24	0.18	0.21
P#30-1%vol	3.67	3.83	3.75	0.11	0.16	0.14
P#30-2%vol	2.45	3.10	2.77	0.11	0.07	0.09

To evaluate the wheel tracking test results, the calculation of proportional rut depth (PRD) is performed as described in Eq. (2).

$$\mathrm{PRD} = \frac{\mathrm{RD}}{\mathrm{Slab\ Thickness}} \tag{2}$$

$$\%\mathrm{Diff} = \frac{|\mathrm{RD\ specimen\ 1} - \mathrm{RD\ specimen\ 2}|}{\min \mathrm{RD}} \times 100 \tag{3}$$

Irregularity of test results was generally found in two specimens with similar test conditions due to the difficulty of controlling large-size aggregate distribution during the specimen preparation process. The rut depth on a specimen may be shallower than it should be when large-size aggregates gather in the area that the test wheel runs through. The acceptance criteria of test results from two specimens with the same aggregate mixture were determined from their proportional rut depth, which was the value derived from a comparison of the proportional rut depth of a specimen at the end of a test with the thickness of its test plate. To avoid bias from the above-mentioned test result irregularity, the test results for both specimens were accepted only when the calculated ratio of PRD1:PRD2, where PRD1 is the larger number, is less than 2.0.

Table 6 presents the proportional rut depth of all tested specimens. It shows that the proportional RD of specimen no. 1 of P#8R#16-2% treatment is 100% different than the result of specimen no.2 of the same treatment. This specimen is considered an outlier and excluded from furthur analysis. Meanswhile, the results of all other specimens are considered acceptable.

Table 6. Comparison of proportional rut depth between specimens after the wheel tracking tests.

Treatments	**Proportional Rut Depth, PRD (%)**		**Ratio of 2 specimens**	**%Diff**	**Result**
	Specimen-1	**Specimen-2**			
control	8.1	6.3	1.3	28.6%	Acceptable
P#8R#16-1%vol	8.1	7.4	1.1	9.5%	Acceptable
P#8R#16-2%vol	12.4	6.2	2.0	100.0%	Unacceptable
P#16R#30-1%vol	8.3	5.8	1.4	43.1%	Acceptable
P#16R #30-2%vol	8.0	7.8	1.0	2.6%	Acceptable
P#30-1%vol	7.2	7.5	1.0	4.2%	Acceptable
P#30-2%vol	4.8	6.1	1.3	27.1%	Acceptable

note: $\%\mathrm{Diff} = |\mathrm{RD\ specimen\ 1} - \mathrm{RD\ specimen\ 2}|/\min \mathrm{RD} \times 100$

The WTS values of all specimens are shown on a bar chart in Fig. 8, and are then replotted in "box plot" style in order to clearly identify the effects of crumb rubber factors on rutting resistance performance of mixtures. Two box plot graphs are presented, the first plot is categorized into groups based on CR particle size as illustrated in Fig. 9 and the other is categorized into groups based on CR content as illustrated in Fig. 10.

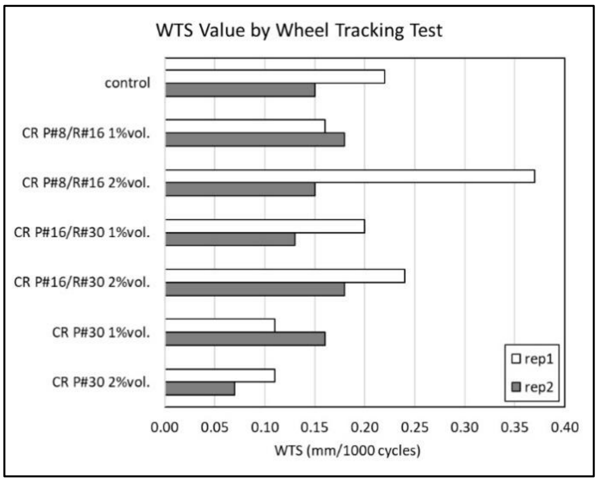

Fig. 8. Plot of WTS values from all treatment cases.

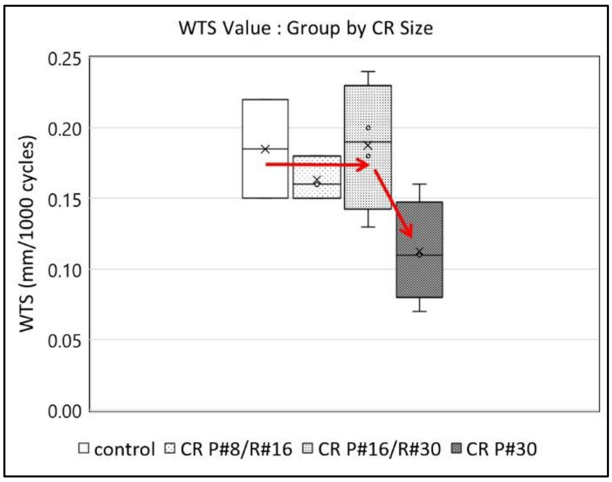

Fig. 9. Box plot of WTS values, categorized by size of CR in mixture.

First, the effect of CR size should be considered. According to the box plot in Fig. 9, the specimens are divided into two groups. The first group comprises control asphalt mixture, asphalt mixture blended with CR P#8R#16 and asphalt mixture blended with CR P#16R#30. The results from this group indicates that mixtures blended with large size and medium sized CR are not significantly different in deformation resistance than the control mixture. The average WTS value of this group is about 0.17 mm/1000 cycles. However, the other group comprises asphalt mixture with CR P#30, whose resulting average WTS is about 0.11 mm/1000 cycles, which demonstrates meaningfully better performance than the first group comprising control mixture and mixtures with the larger size of CR. A possible explanation of CR size P#30 significantly outperforming the other cases may be because it coud infuse to asphalt cement better than the others. This was likely because P#30 had the larger contact surface area per unit volume than the other cases. And CR P#30 particle size was smaller than 0.6 mm which was similar to the CR size used in the wet process modification [20]. The CR P#30 specimens might experience a partial wet process infusion during the specimen standard curing process in an oven at 150°C for 2 hours before compaction [21, 24].

Second, the effect of CR content on the rutting resistance is considered. Figure 10 illustrates that the CR content in the specimens has a significant effect on the deformation resistance performance of the mixture. The graph shows that the average WTS value from the controlled specimens is 0.19 mm/1000 cycles. The average WTS values from the specimens with 1% CR and 2% CR is reduced to 0.16 mm and 0.15 mm/ 1000 cycles respectively. This indicates that the specimens with higher content of CR have better deformation resistance than those with lower CR content.

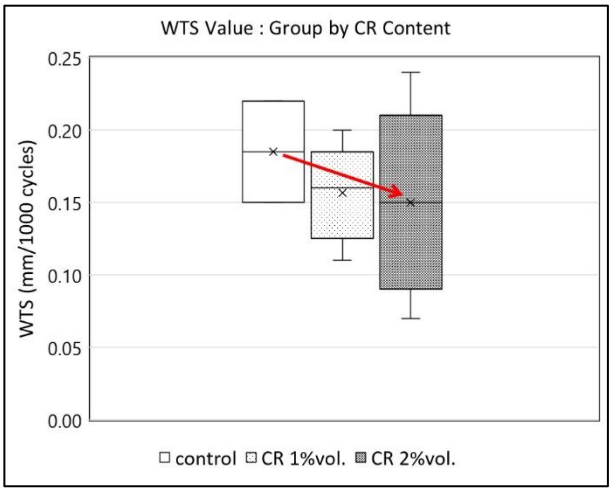

Fig. 10. Box plot of WTS values, categorized by CR content in mixture.

5. Conclusions

The asphalt mixture modification using crumb rubber with "Dry Process" technique in this study points to blending crumb rubber particles into asphalt mixture as a substitute for the same sized limestone aggregate in some portion as the preferred option. Following the methodology and testing criteria of this study, this modification to the conventional HMA production during mixing period could easily be adopted. The mixture produced using this process was able to be mixed and well compacted. Therefore, this modification method has potential for upscaled industrial use. Crumb rubber could be added in the pugmill of an industrial production plant during mixing process between asphalt binder and aggregate.

The performance of CRM HMA with regard to permanent deformation resistance (or rutting resistance) was investigated using Wheel Tracking Test. The results indicated that the rutting resistance of CRM asphalt mixture is improved when compared to the conventional mixture. The factors that influenced to this improvement were particle size and quantity of crumb rubber (CR) in the mixture. The findings were summarized as follows.

1) For the CR particle size, mixtures that contained with large and medium CR particle (1.18-2.36mm and 0.6-1.18mm) showed no significant difference in performance from the unmodified one, while mixture with CR particles smaller than 0.6mm showed excellent performance, indicated by significantly lower WTS value than other mixtures.
2) For CR quantity, the test results indicate that the mixture with a higher content of crumb rubber has a better performance in rutting resistance. According to this study, the mixture blended with small sized crumb rubber by 2% of total aggregate volume (or 0.8% of total asphalt mixture weight) performed 2.1 times better than the conventional HMA.

Therefore, it can be concluded from this study that the crumb rubber modified asphalt mixture using dry process has shown a significant improvement in permanent deformation resistance that is better than the conventional asphalt mixture. Lastly, it should be noted that the number of repeated specimens used in wheel tracking test were limited to two per case. Furthur study on additional specimen testing will be helpful to strengthen the repeatability of this conclusion.

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