UTILIZATION OF RECYCLED PLASTIC AND NATURAL RUBBER IN ASPHALT CONCRETE TO IMPROVE PERFORMANCE OF FLEXIBLE PAVEMENT: LABORATORY INVESTIGATION

Arun Lukjan[1*], Akkachai Phoonnual[2], Chuthamat Laksanakit[1], and Saravut Jaritngam[3]

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Abstract

The purpose of this study is to investigate the feasibility of using recycled low density polyethylene (LDPE) plastic and natural rubber (NR) as a polymer additive in asphaltic concrete pavement. In this work, 60/70 penetration grade asphalt cement (AC) was modified by varying the percentage of NR of 2, 3, and 4% by mass of AC based on the wet process, while the aggregate was blended with LDPE at the same content as the NR following the dry process and then mixed together. The polymer modified asphalt concrete (PMAC) specimens were prepared based on the Marshall mixed design procedure, designed for the binder coarse layer. The result showed that the PMAC, by adding 2.5% LDPE and 2.5% NR by mass of optimum binder content (4.90%), can enhance both the volumetric and mechanical properties of the mixture with better durability, rutting resistance, and stiffness than conventional asphalt concrete.

Keywords: Asphalt, recycled plastic, natural rubber, modified asphalt concrete, Marshall method

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[1] *Department of Civil Engineering, Faculty of Engineering, Rajamangala University of Technology Srivijaya, 90000, Thailand. Tel.: +08-9737-7356; E-mail: federun9@gmail.com*
[2] *Bureau of Central Land Consolidation Royal Irrigation Department, 94170, Thailand.*
[3] *Department of Civil Engineering, Faculty of Engineering, Prince of Songkla University, 90110, Thailand.*
[*] *Corresponding author*

Introduction

Polymer modified asphalt (PMA) has been used on flexible pavement to improve the properties of hot mix asphalt (HMA) for the past 2 decades. A significant advantage of the polymers when used as an additive on HMA is improved mechanical properties such as the rutting resistance, thermal cracking, stripping, and fatigue damage (Becker *et al*., 2001). Polymers used to modify an asphalt mix can be categorized based on deformation into 2 groups, namely elastomers and plastomers. Moreover, heating behavior is also used to class polymers like thermosetting and thermoplastic. Elastomers typically include copolymers of styrene and butadiene, crumb rubber, and natural rubber. Plastomers include ethylene vinyl acetate, low or high density polyethylene (LDPE or HDPE), and various compounds based on polypropylene (Aire, 2002; Awwad and Shabeeb, 2007; Al-Hadidy and Tan, 2009).

There are many applications of PMA such as natural rubber (Tuntiworawit *et al*., 2005; Dechasakulsom, 2012; Vichitcholchal *et al*., 2012; Al-Mansob *et al*., 2014; Shaffie *et al*., 2014; Wen *et al*., 2015), crumb rubber tire (Cao, 2007; Lee *et al*., 2008), recycled LDPE/HDPE plastic (Panda and Muzumdar, 2002; Hinisliglu and Agar, 2004; Awwad and Shabeeb, 2007; Punith *et al*., 2011), and crumb rubber with LDPE (Malarvizhi *et al*., 2012) with its use as an additive being described in the literature. Most researchers explored similar results that PMA can enhance the mechanical performances of a flexible pavement. It was concluded that the optimum polymers' content ranged between 2-10% by mass of asphalt cement (AC) (Kalantar *et al*., 2012). Additionally, in 2014 the amount of solid waste in Thailand was about 26.19 million tons. There was a significant increased trend of 1 million ton/yr. Approximately 30% of domestic waste can be reused and about 16% of that was a variety of plastic (Pollution Control Department, 2015). In 2016, most of the plastic production was obtained from about 70000 tons of carrier bags (55% of the plastic goods) (Photjit, 2017).

Although many researchers have significantly pointed out the advantage of plastomers polymers (e.g.,HDPE or LDPE) used with HMA, they really have not yet been adopted in Thailand. Recently, the Thai government has promoted NR as a flexible pavement mix. The Department of Highways subsequently recommended the proportion of NR modifier as 5% by mass of AC (Dechasakulsom, 2012). Therefore, to promote the use of NR as a consequence of the government policy and to concurrently reduce the plastic waste, the use of 2 such modified polymers used in pavement is investigated.

This paper presents an experimental study that investigates the plausibility of using recycled LDPE plastic from carrier bags and natural rubber (NR) as a modifier asphalt concrete mix for the binder course layer. The volumetric and mechanical properties of the modifier polymer asphalt concrete were calculated and evaluated with the Marshall method.

Materials and Methods

Materials

The materials used as a hot mixture asphalt in this study comprised aggregates, asphalt cement (AC), and modified polymer. The coarse and fine aggregates were tested based on the Thai Department of Highways' Standards (DH-S). The physical properties of those aggregates and adopted gradation are shown in Table 1 and Figure 1. Based on the gradation criteria for the binder coarse surface, the proportions for aggregate (hot bin 1:2:3:4) of 47:22:18:13 were used. The asphalt cement used in this study was AC 60/70 penetration grade that is widely used for HMA pavement in Thailand. Its specific gravity is 1.02. The modified polymers included NR and recycled LDPE. The thermoplastic LDPE obtained from carrier bags was prepared with a size of 2 mm×2 mm (Punith *et al*., 2011) before blending with the aggregates.

Methods

Preparation of the Marshall Specimens

In this study, the Marshall specimens were categorized into 2 groups. The first group was the control asphalt concrete (CAC) that was prepared based on the Marshall mixed design procedure, as specified in the DH-S 408 (Department of Highways, 1989). The second group was polymer modified asphalt concrete (PMAC) that was prepared based on the DH-S 416 (Department of Highways, 2013). Both the CAC and PMAC specimens were designed for use as the binder coarse surface (40-80mm) which supports heavy traffic. The Marshall method was conducted in accordance with ASTM D1559 (ASTM, 1989).

For the CAC, 3 specimens were prepared for each AC content which had varied percentages of AC at the rates of 4.0%, 4.5%, 5.0%, 5.5%, and 6.0% by mass of aggregate in order to define the optimum binder content (OBC). Thus, a total mixture of 15 specimens was prepared for the CAC group. PMAC is an asphalt concrete mixture of aggregate, AC, NR, and LDPE. For the PMAC, the AC content varied the same as the CAC specimens. The additive content in this study was varied by 2%, 3%, and 4% by mass of AC for both the NR and LDPE. Thus, a total of 45 specimens was prepared for the PMAC. The details of the total the Marshall specimens are shown in Table 2.

Marshall Method

Because the CAC specimens were prepared based on the conventional Marshall

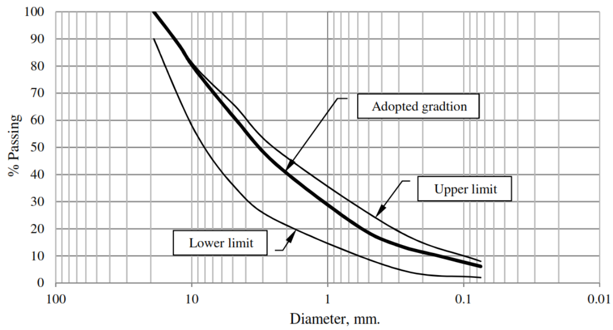

Figure 1. Grain size distribution curve of aggregate

Table 1. Physical properties of aggregate

Physical Properties	Fine aggregate Bin 1 (Stone dust)			Coarse aggregate			Total	Specification (Department of Highways, 1989)
	#200 P	#200 R	Total	Bin 2 (3/8")	Bin 3 (1/2")	Bin 4 (3/4")		
Mix proportion, %	-	-	47	22	18	13	100	-
Bulk spec. gravity	-	2.698	2.699	2.688	2.685	2.692	2.693	-
App. spec. gravity	2.709	2.700	2.701	2.703	2.704	2.713	2.703	-
Water absorption, %	-	0.82	-	0.58	0.46	0.34	-	-
Flakiness index, %				23	24	25	24	< 30%
Elongation index, %				20	21	23	21	< 30%
Asphalt absorption, %							0.25	-
LA. abrasion, %	Hot bin 4 = 26							< 40%
Soundness, %	Hot bin 1 = 5.2			, Hot bin 4 = 2.5				< 9%
Sand equivalent, %	Hot bin 1== 73							> 50%

Note: P =Passing; R=Retained

method, only preparation of the PMAC specimens will be described in this section.

1) Compaction of the Marshall specimens

Both the dry and wet processes were conducted for the PMAC. The dry process included mixing the LDPE with aggregates prior to addition to the modified asphalt; the temperature for mixing was kept at 170±10°C (Punith *et al.*, 2011; Department of Highways, 2013), while the wet process was a mixture of the AC with NR with a temperature of 170±5°C before the mix as the Marshall specimens. Then, the mixture of aggregate and LDPE (from the dry process)was mixed together with the AC and NR (from the wet process) within 1 min (Department of Highways, 2013).

Then, the mixture was placed in a preheated standard mold and compacted; 75 blows with a mechanically operated compaction hammer were applied to both faces of the specimen. The compacted specimens were cooled to room temperature before de-molding. The thickness of the specimens was measured and they were weighed in air, immersed, and saturated in surface dry conditions in order to determine the Marshall density.

2) Marshall stability and flow test

The specimens were brought to the specified temperature (60°C) by immersion in a water bath for 45 to 60 min. The specimens were removed from the water bath and placed immediately into a breaking head. A load was applied to the specimens by means of a constant rate of 50 mm/min. The maximum load was recorded as the stability value, although the deformation at the maximum load is the flow value.

Results and Discussion

The average values of density, stability, flow, air void, void in mineral aggregate (VMA),

Table 2. Preparation of the Marshall specimens

No.	Specimens	%AC	%NR	%LDPE	Total of specimens
1	Control asphalt concrete (CAC)	4.0, 4.5, 5.0, 5.5, 6.0	-	-	3×5 = 15
2	Polymer modified asphalt concrete (PMAC)	4.0, 4.5, 5.0, 5.5, 6.0	2, 3, 4	2, 3, 4	3×5×3 = 45

Table 3. The Marshall result of control asphalt concrete (CAC)

Sample No.	AC (%)	Density (g/cm^3)	Air void (%)	VMA (%)	VFB (%)	Stability (lbs.)	Flow (0.01")
1	4.0	2.352	6.51	14.71	55.76	2450	11
2	4.5	2.381	4.75	14.09	66.56	2610	12
3	5.0	2.385	4.05	14.45	72.32	2650	13
4	5.5	2.371	3.75	15.25	75.07	2600	14
5	6.0	2.346	3.18	16.54	74.71	2490	15
Optimum	5.00	2.385	4.00	14.20	72.50	2650	13
Specification (Department of Highways, 2013)	3-6.5	-	3-6	≥13	65-75	≥ 1800	8-16

and void filled with bitumen (VFB) obtained from the specimens were plotted separately against the AC content. For the CAC, the AC content corresponding to an air void of 4% is considered as the OBC. Table 3 shows the Marshall results of the CAC mix in which the optimum value is represented by the mix that is 5% by mass of aggregate.

In order to describe the influence of the additive content on the HMA properties, both the volumetric and mechanical (engineering) properties of the PMAC mix have been considered. For this mix, the OBC can be determined by being defined as an average asphalt content value at 4% air void, the midpoint of the specification range for the VFB, and maximum stability (Asphalt Institute, 1993). In this study, the OBC of 4.90% was observed and then used as the average value to determine the Marshall properties for all mixes. The percentage of additives by mass of AC have been plotted against the corresponding Marshall properties.

Volumetric Considerations

The volumetric properties include air voids, VMA, VFB, and bulk density. Air voids are the spaces within the mixture and are inversely proportional to the AC content. The VMA is defined as the inter-granular void space between the aggregate particles in a compacted asphalt mixture. The VFB is described as the percent of the volume of the VMA that is filled with bitumen. The density and voids are directly correlated which helps to control the performance of the HMA.

The relationship between the air void and AC content with varied percentages of additives compared with the CAC specimen is shown in Figure 2(a). The result in Figure 2(b) represents a decrease in the air void with increasing percentages of NR and LDPE. All mixtures of MPAC show a clearly decreasing trend of air void with R^2 of 0.9868 which is less than the value of the CAC mix. However, the values remained within the available range of 3-5% which supports the use of these additives. Figure 3(a) shows the relationship between the VMA and AC content of the MPAC compared with the CAC. Figure 3(b) represents a slight decrease in the VMA values to a minimum value and then an increase with increasing percentages of the NR and LDPE. The curve in Figure 3(b) shows that the value of the VMA is not lower than a minimum criterion (13%). Conversely, the variation of the VFB in Figure 4(a) depicted an increase in the VFB with increasing percentages of the AC content. The influence of the NR and LDPE on the VFB values for the PMAC mix is observed in Figure 4(b) which shows that all the additive contents are scattered in an allowable specified

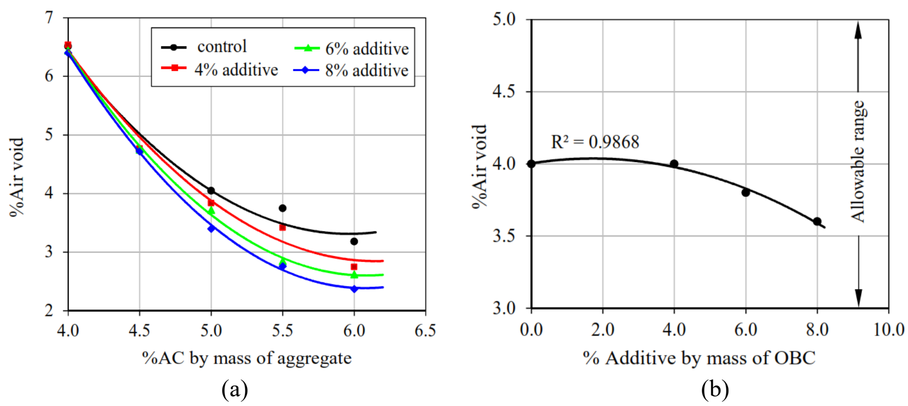

Figure 2. (a) Variation of air void and AC content and (b) influence of NR and LDPE on air void value with different percentage of additive

range. From the above-mentioned, it may be explained that these volumetric parameters indicated the influence of the additive contents on the optimum binder content.

The bulk density of the PMAC mixture with various contents of additives compared with the CAC specimen is shown in Figure 5(a). Figure 5(b) depicted that, as the percentages of the NR and LDPE increase, the bulk density value increases initially, reaches a maximum, and then decreases. This implied that the increase of bulk density causes the reduction of the air void in the mixture.

Mechanical Considerations

The mechanical considerations on the Marshall properties consist of the stability and flow values. The strength of the compacted specimens are measured in terms of the Marshall stability. The peak of the stability curve observed in all mixes, as shown in Figure 6(a), increases with increasing the asphalt content up to a maximum after which the stability decreases. Figure 6(b) shows the influence of the NR and LDPE on the Marshall stability, represented by an increase in stability with the increasing percentages of the NR

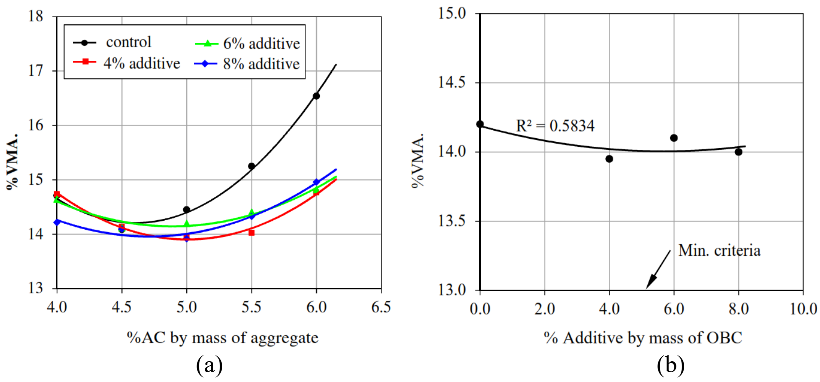

Figure 3. (a) Relationship between VMA and AC content and (b) influence of NR and LDPE on VMA value with different percentage of additive

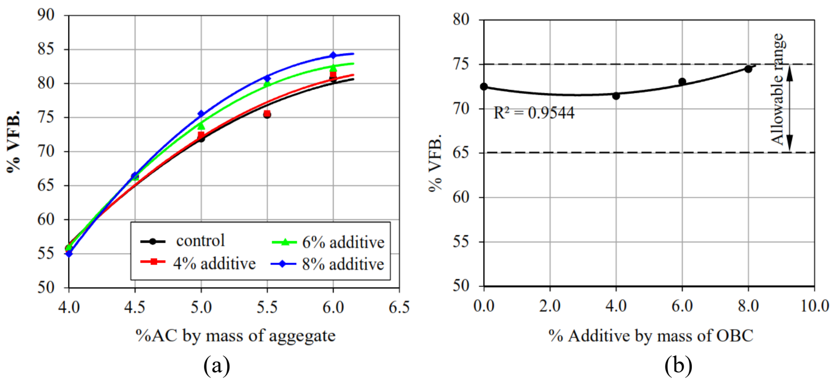

Figure 4. (a) Relationship between VFB and AC content and (b) influence of NR and LDPE on VFB value with different percentage of additive

and LDPE. An increased trend with a high correlation coefficient R^2 of 0.9889 shows clearly the enhancement of the strength property of the HMA.

The flexibility of the Marshall specimen is measured in terms of the flow value. Figure 7(a) depicts an increase in flow values with the increasing asphalt content for all mixes. Figure 7(b) shows the influence of the NR and LDPE on the Marshall flow for the PMAC. Similar to the stability trend, it presents an increase in the flow value with the increase of the NR and LDPE contents. However, the result in Figure 7(b) indicated that the flow value is over the specified range when used with the addition of over 7% of polymer modified asphalt.

Evaluation the Marshall Result

From the effects of the NR and LDPE on the Marshall properties obtained in this paper, the 5% additive (i.e., 2.50% NR and 2.50% recycled LDPE plastic) is recommended as a suitable additive content which satisfies the desired volumetric and mechanical parameters. Thus, the 5% additive will be used to define the optimum for the Marshall

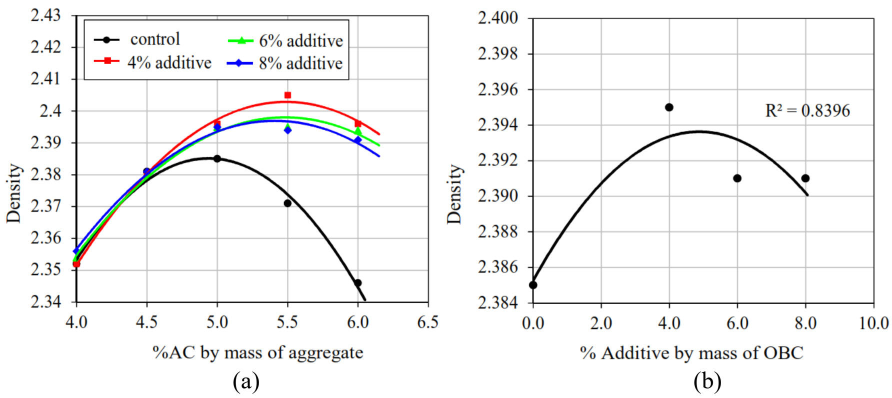

Figure 5. (a) Variation of bulk density and AC content and (b) influence of NR and LDPE on bulk density value with different percentage of additive

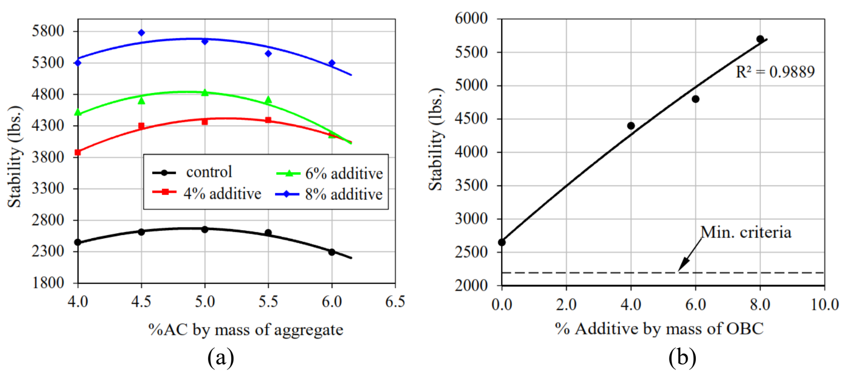

Figure 6 (a) Relationship between the stability and AC content and (b) influence of NR and LDPE on Marshall stability value with different percentage of additive

properties to assess the impact of polymer on the HMA. The result of the Marshall parameters obtained for both the CAC and MPAC are shown in Table 4, and all values have satisfied the requirements of the given specifications.

The bulk density of the MPAC curve encountered the maximum density of 2.393 g/cm^3 with a coefficient of determination R^2 of 0.8396. The density is a slight increase of about 0.34% of the CAC density (2.385 g/cm^3), and indicated a better durability of the mix. This characteristic is an effect of the reduction of the air void, VMA, and VFB of the mix. They decreased about 2.50, 1.41, and 0.69%, respectively. The decrease of the VFB led to a reduction of the effective bitumen film thickness between aggregates. The correlation between all voids and the asphalt content can be explained by a reduction of the OBC, which decreased from 5.00% to 4.90%. Moreover, a change of the AC was replaced by the additive used in this study.

An increase of about 74% of the Marshall stability was found in this paper. This behavior can imply that it affected the mixing processes of the LDPE and aggregate. The mineral aggregate was coated by the LDPE which increased the interlocking or frictional resistance on the aggregate and contact area between the asphalt and polymer. A high stability value indicated a higher rutting resistance. Likewise, the Marshall flow was observed as a 19.23% increase compared to the conventional HMA. In fact, the high flow values indicate an HMA that has a plastic

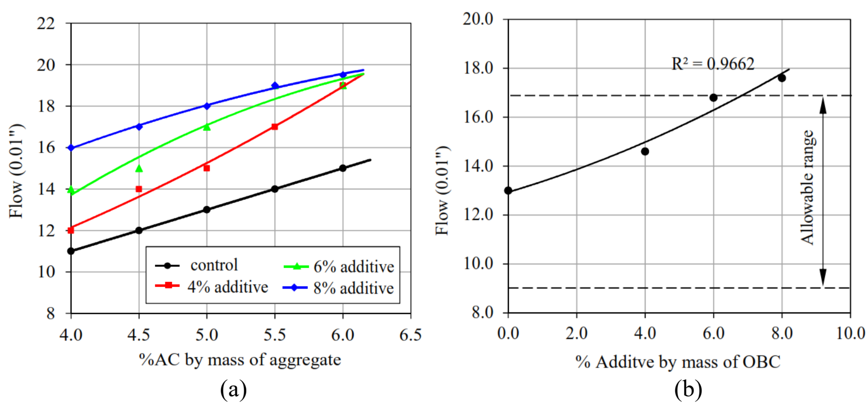

Figure 7. (a) Relationship between the flow value and AC content and (b) influence of NR and LDPE on Marshall flow value with different percentage of additive

Table 4. The Marshall result of PMAC at optimum bitumen content

	OBC (%)	Density (g/cm^3)	Air void (%)	VMA (%)	VFB (%)	Stability (lbs.)	Flow (0.01")	MQ (lb/0.01")
CAC	5.00	2.385	4.00	14.20	72.5	2,650	13	203.85
MPAC with 5% additive [a]	4.90	2.393	3.90	14.10	72	4,600	15.5	296.80
Specification (ASTM, 1989)	3 - 7	-	3 - 5	≥ 13	65-75	≥ 2,200	9 - 17	≥ 170
% deviation	-	+ 0.4	- 2.56	- 1.41	- 0.69	+ 73.58	+ 19.23	+ 45.8

[a]MPAC mixture at 2.50% natural rubber, and 2.50% recycled LDPE of optimum binder content (4.90%).
MQ =Marshall Quotient

behavior and has the potential for permanent deformation such as rutting or shoving under loading. However, the flow value (15.50) is located within the required specification range of 9-17. The Marshall Quotient (Table 4) demonstrates the ratio of load to deformation (stability/flow). In this study, about a 45% increase indicated that the MPAC provides a better mixture stiffness.

Requirement of LDPE and NR Quantity

To describe the quantity of the recycled LDPE and NR when used as an HMA modifier in flexible pavement, the following example would be useful.

When designing an asphalt binder course layer of 80 mm thickness, a highway width of 10 m, and a 1 km length, the density of the MPAC = 2.393 ton/m^3, the OBC = 4.90%, the recycled LDPE plastic content = 2.50%, and the NR content = 2.50% (by mass of OBC).

Thus, the mass of recycled LDPE and NR required

$$= 0.05 \times 0.049 \times 2.394 \times 10 \times 1000 \times 0.08$$
$$= 4.70 \text{ tons.}$$

From this example, the calculation can be made that the amount of recycled LDPE plastic is 2.35 ton/km and natural rubber is 2.35 ton/km.

Conclusions

This paper attempts to investigate the performance of modified polymer asphalt concrete (MPAC) by utilizing recycled LDPE plastic obtained from carrier bags and natural rubber (NR) as an additive. The main goal of this study is to define the appropriate mixture of the HMA used as a binder course layer supporting heavy traffic. It is concluded that the MPAC, by the addition of 2.5% recycled LDPE and 2.5% NR by mass of optimum binder content (4.90%) can improve both the volumetric and mechanical properties of the mixture. The increase of density, stability, and Marshall Quotient indicated better durability, rutting resistance, and stiffness, respectively, over the conventional control mix.

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