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Improving the Properties of Asphalt Concrete Using Waste Plastic Bottle as Additive

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Abstract— Disposal of waste plastic bottles are hazardous for environment as they are non-biodegradable. In this study waste plastic bottles were used as additive to investigate whether it would improve the properties of asphalt concrete. For this purpose four different series of asphalt concrete samples were produced using shredded waste plastic bottle in different proportions (0%, 0.25%, 0.50%, and 0.75% by weight of total aggregate and five different percentages of asphalt (4.5%, 5.0%, 5.5%, 6.0% and 6.5% by weight of total aggregate). The amount of optimum asphalt content, the value of retained stability and all Marshall properties were determined for these samples. It has been seen that using 0.75% additive which gave the highest stability with the lowest optimum asphalt content. It was also observed that using this additive the Marshall properties of asphalt concrete have improved. This investigation also indicates that waste plastic bottle can conveniently be used as a modifier in asphalt concrete to ensure sustainable reuse of plastic waste as well as improve the properties of asphalt concrete.

Index Terms—Waste plastic; Non-biodegradable; Asphalt concrete; Marshall properties; Additive; Optimum asphalt content; Retained stability.

1 Introduction

Asphalt concrete is commonly used in the construction of flexible pavement all over the world. Nowadays asphalt concrete pavement is expected to perform better because of increased traffic volume in terms of commercial vehicles, increased traffic load and seasonal temperature variations. This demanding situation necessity the thinking of some alternatives for improving the properties of asphalt concrete using some modifiers to address both the strength and economical aspect.

Various types of waste materials are generated due to industrial growth with a growing population. Disposal of large amount of waste especially non-biodegradable waste has created various types of problem and produces harmful effect on environment. It was reported that 13,332.89 ton/day waste are generated from aluminum, glass, plastic, paper, bones and polythene in Bangladesh [1]. It was also observed that 4635.52 ton/day solid wastes are generated in Dhaka city of Bangladesh only and among them 137.57 ton/day of wastes are plastic [2]. So these huge amounts of plastic waste are harmful for city. According to [3], the best way to get rid of the excessive solid wastes accumulating in urban and industrial areas is to implement the reuse of waste material. This initiative would have a significant impact on both the environment and the economy in some ways. In fact, they are usually discharged into landfills as waste material. As a result, huge environmental pollution including soil and water contamination have been observed due to their disposal reasons [4].

The use of waste plastic with bitumen is similar to using polymer modified bitumen. The authors observed that using discarded plastic materials as an additive the properties of asphalt concrete (AC) have been improved. It was also seen that the polymers could be used effectively in the modification bitumen for the construction of ductile pavements [5]. According to Jassim et al. [6], using 15% waste plastic (by wt. of total aggregate) in hot mix asphalt the Marshall stability and resistance to water damage have been increased. Vamshi [7] stated that addition of waste plastic in hot mix asphalt not only modified the properties of bitumen but also reduced the construction costs of road. The sound pollution of heavy traffic has also decreased using this waste in road construction. During the last few decades many researchers in many countries around the world reported that modification of the bitumen binder with polymer additives can enhance the properties and life of AC pavements. Other researchers Zoorab and Suparma [8] stated that using plastic which are mainly composed of polythene and low density polythene in HMA the durability and fatigue life are found better as compared to conventional one. An increase by 20% in stability and about 30% in indirect tensile strength (ITS) were observed with mixes modified using plastic wastes. Gawande et al. [9] reported that an addition of 5 to 10% waste plastics by weight of bitumen the Marshall stability, strength, fatigue life and other desirable characteristics of bituminous concrete mix have significantly improved.

In this study, the waste plastic bottles that are collected from a popular drinking water brand “MUM” made of polyethylene terephthalate (PET) is used in shredded form of about (1×10) mm sizes in hot mix asphalt concrete as a modifier to improve the properties of asphalt concrete.

2 Materials

2.1 Aggregate

Stones are most commonly used in asphalt concrete as aggregate. The different properties of aggregate have a large impact on the stability, flow, and different Marshall properties of asphalt concrete. Locally available aggregate were used in this study. The properties of used aggregate are shown in Table 1.

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Table 1 Physical properties test results of aggregate

Test name	Test Standard	Result (%)	Standard Value
LAA	AASHTO T 96	19.12	≤30
AIV	BS 812: Part 110: 1992	19.30	≤25
ACV	BS 812: Part 110: 1992	22.81	≤30
EI	BS 812: Section 105.2: 1990	22.42	≤30
FI	BS 812: Section 105.1: 1990	22.50	≤30
Sp. G (C.A , F.A)	AASHTO T 85	2.65, 2.74	-

2.1.1 Gradation of aggregate

The stone aggregates of various sizes are used in asphalt concrete. The particle size distribution of stone aggregate is termed as gradation. The sieve analysis is conducted to determine the particle size distribution. In this study, stone aggregates were screened by ASTM specified sieve ¾ inch to #200.The combined gradation of aggregate and filler are shown in Table 2.

Table 2 Selected combined gradation of aggregate and filler

Coarse Aggregate (C. A) = 52%, Fine. Aggregate (F. A) = 42% & Mineral Filler (M. F) = 6%

Sieve size	% Passing	Specified limit	Cumulative % Retained	% Used
3/4"	100	100	0	0
1/2"	97.4	90-100	2.6	2.6
3/8"	80.76	76-90	19.24	16.64
#4	61.52	44-74	38.48	19.24
#8	47.14	28-58	52.86	14.38
#40	33.30	8-27	66.70	13.84
#80	16.92	5-17	83.08	16.38
#200	06	5-8	94	10.92
#200 (Retained)			100	6
			Total	100

2.2 Mineral Filler (M. F)

The fillers are sieved through No. 200 sieve. It offers permeability and also stiffens the binder as well as fill the voids in aggregates. In this research work stone dust is used as filler with specific gravity of 2.57.

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2.3 Asphalt

Asphalt is used in aggregate as binding materials and it also acts as a filler and stabilizers in asphalt mixture. It offers impermeability and particle adhesion because of asphalt fills the void. The properties of used asphalt are shown in Table 3.

Table 3 Physical properties test results of asphalt binder

Test name	Test standard	Test value	Standard value
Penetration grade	ASTM D 5-86	60/70	-
Softening Point	ASTM D 36-70	51ºC	30ºC to 157ºC
Spe. G	ASTM D 70-76	1.02	0.97 to 1.02
Ductility	ASTM D 113-86	100+	Minimum 50
Flash point	ASTM D 92-90	308ºC	Minimum 175ºC
Fire point	ASTM D 92-90	337ºC	Minimum 200ºC

2.4 Waste plastic bottle

Waste plastic bottles (WPBs) were collected from locally available sources. The collected WPBs were cleaned by water then sun dried. Finally the cleaned WPB shredded into small pieces i.e. approximately (1×10) mm sizes. The photo view of WPB has been shown in Figure 1 and 2.

Fig. 1: Collected WPBs

Fig. 2: Shredded WPBs

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3 Experimental work

3.1 Preparation of Marshall specimen

The samples for bituminous concrete mixtures were prepared as per ASTM D1559 with different bitumen contents. As a first step in the procedure, the aggregates with the proper graduation are thoroughly dried and heated. Sufficient mixture was generally prepared at each asphalt content. Each specimen required approx- imately 1.2 kg of mixture. Then the asphalt and the aggregates were heated separately and then mixed. Next the additive was mixed in HMA. Finally, the mixture was placed in the mold, mixed by hand with a trowel, and compacted. After compacting the mold was placed air cooled for 30±5 minutes and then the specimen was removed from mold after predefined time. After removing the sample, the required dimensions are taken and then submerged into the water bath at 60ºC for 35 ± 5 minutes. The some photo view of experimental work as shown in Figure 3.

Fig. 3: Photo view of (a) materials mixing (b) sample placing in water

3.2 Marshall stability and flow

After completion of the required time in water bath the sample was placed in Marshall Stability tester machine to determine sta- bility and flow value. All samples were tested under this Marshall Stability machine. Stability was measured in kN and flow value was measured in mm. A view of Marshall stability tester machine with specimen has been shown in Figure 4.

Fig. 4: Marshall stability testing machine

4 Results and discussions

4.1 Density void analysis

After completing the stability and flow tests, a density and voids analysis were made for each series of test specimens and the following graphs are plotted as shown in Figure 5 through 10.

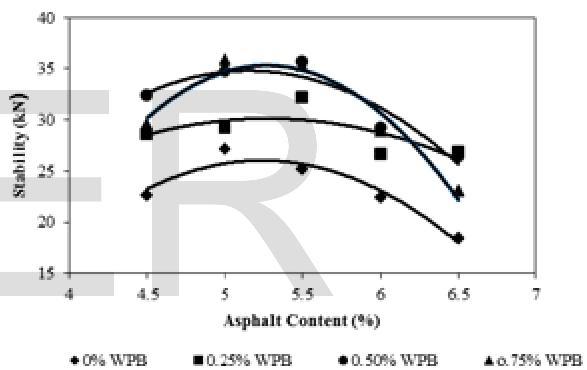

Fig. 5: Asphalt content vs Stability curve

The stability values for all samples were determined and these values are shown in Figure 5. It is clearly seen from the Fig. 5 that stability of asphalt mix increases as the bitumen content increases till it reaches the peak with bitumen content of 5.0% and then it started to decline gradually with higher bitumen content. The maximum stability for conventional mix is found as 26 kN and for modified mixes with 0.25%, 0.50% and 0.75% of WPB the maximum stability were found 30.2kN, 34.6kN and 36.1 kN respectively. Marshall stability values increases with increase in WPB content.

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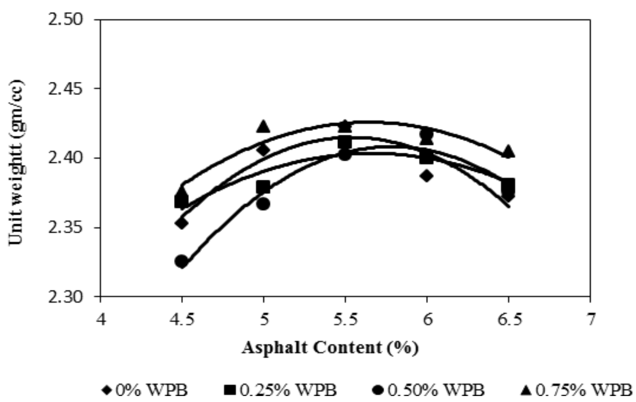

Fig. 6: Asphalt content vs Unit wt. curve

The unit weight values of all samples have been shown in Figure 6. It is observed from graphs that the unit wt. increases as the bitumen content increases till it reaches the peak with bitumen content of 5.5%, then it started to decline gradually with a higher bitumen content. It is also seen that the unit wt. values of conventional mix are higher than the modified mix. The 0.75% WPB added modified mix shows minimum unit wt. value.

Flow value (in mm) is represented the total amount of deformation which occurs due to application of load. It is observed from the Figure 7 that flow value of asphalt mix decreases as the bitumen content increase till at 5.5% then it started to go gradually up to a higher bitumen content. When binder is applied in a mixture the aggregate absorbs first the binder and then binder fills the void of mixture. So the flow value initially decreases up to certain limit before it increases with increasing percentage of asphalt content. Flow value of modified mix is lower as compared to conventional mix. All the values are within permissible limit except with 6.5% asphalt content.

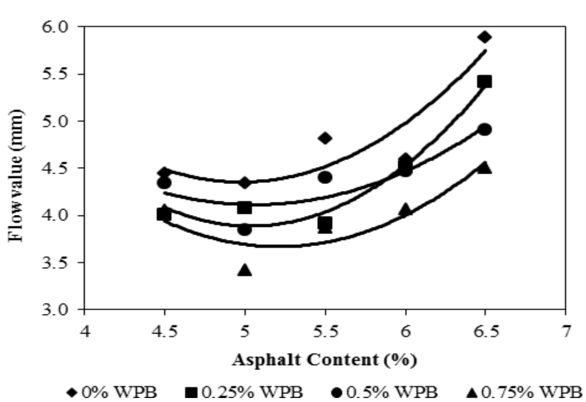

Fig. 7: Asphalt content vs Flow value curve

The air void curves have been shown in Figure 8. It is seen that the percentage of air void have decreased with increased asphalt content. When binder is applied in a mixture the aggregate first absorbs the binder and then binder fills the void of mixture. So the air void (%) have decreased in the mixture with increased the asphalt content (%). The value of air voids for modified mix is lower than the conventional one. Minimum air void is obtained for modified mix with 0.75% WPB.

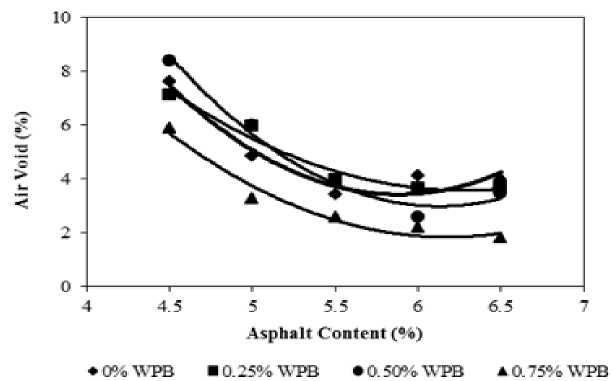

Fig. 8: Asphalt content vs Flow value Curve

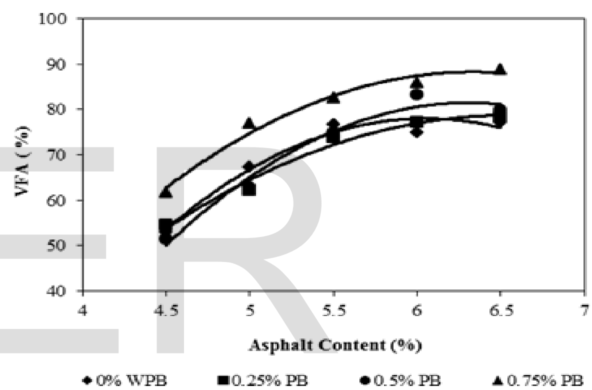

Fig. 9: Asphalt content vs VFA (%) curve

It is seen from Figure 9 that VFA (void filled with asphalt) value increases with increase in asphalt content for both the convention the maximum VFA value. Maximum VFA value is found when 0.75% WPB is added to the mixture.

It is seen from Figure 10 that VMA (void in mineral aggregate) value of asphalt mix decreases as the bitumen content increases till 5.5% and then it started to go gradually up to higher bitumen content. When binder is applied in a mixture the aggregate first absorbs the binder then binder fills the void of mixture. As a result, VMA value has increased.

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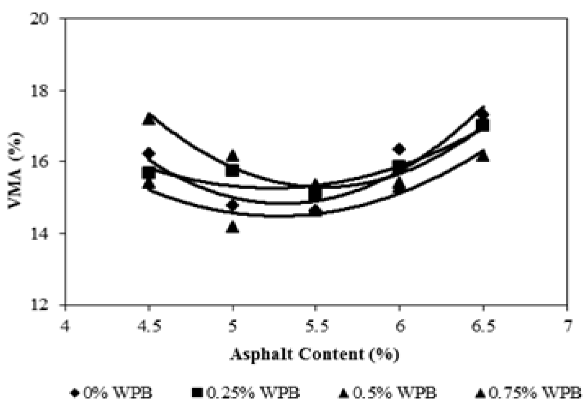

Fig. 10: Asphalt content vs VMA (%) curve

4.2 Optimum test result

The summary of optimum test result are shown with the help of Figure 11 and Table 4.

It is seen from figure 11 and table 4 that all the properties of asphalt concrete mixture containing (0, 0.25, 0.50 & 0.75)% WPB by wt. of total aggregate satisfy permissible value except the flow value of (0, 0.25, & 0.75)% WPB. But these values are slightly higher than permissible maximum value. It is also seen than when the percentage of WPB increases the values of stability, VFA have increased while the value of air void, flow value and VMA have decreased. The unit wt. is almost same for all samples and the retained stability values initially increase from 73 to 85 and then reduces to 76 with 0.75% WPB. But, these values are within the permissible limit.

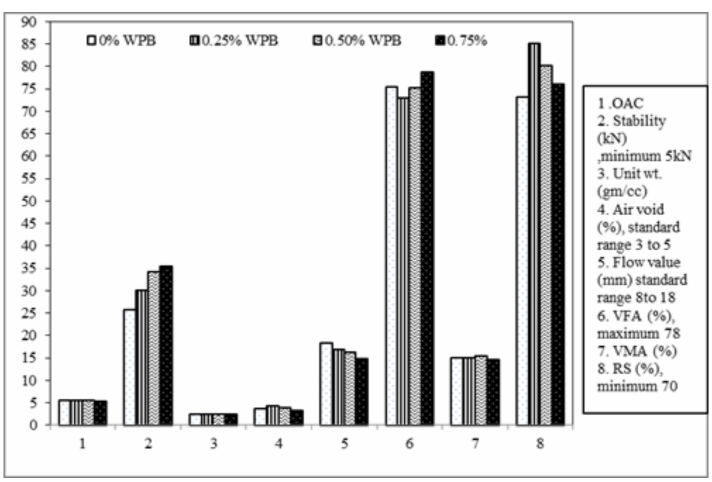

Fig. 11: Results summary with respect to OAC

Table 4 Results summary with respect to OAC (it helps to find out optimize percentage of WPB)

Properties	WPB%				Standard value
	0	0.25	0.50	0.75	
OAC (%)	5.53	5.55	5.50	5.21	
Stability (kN)	25.59	29.91	34.81	35.28	5 kN (min)
Unit Wt. (gm/cc)	2.42	2.41	2.40	2.40	
Air void (%)	3.67	4.19	3.79	3.11	3 - 5
Flow Value (mm)	4.54	4.20	4.07	3.67	2 - 4
VFA (%)	75.27	72.84	75.21	78.69	65 - 78
VMA (%)	14.90	15.0	15.40	14.50	
Retained stability (%)	73	85	80	76	70 (min)

From our study, we have shown that the waste plastic worked as a binder in asphalt concrete mixture. So when the amount of plastic increased, the value of air void and VMA reduced. Moreover, the plastic is found to make good bonding with aggregate and asphalt, due to which the stability has increased while the flow value has decreased.

5 Conclusion

In the end it may be suggested that mixing WPB with asphalt concrete mixture gives a better result than conventional mix and improves its properties with increasing amounts of WPB. In our study it is observed that 0.75% WPB being added to asphalt concrete mixture can yield better results than (0, 0.25 and 0.50)% WPB added asphalt concrete mixture. Finally, it can be concluded that using WPB in asphalt concrete mixture not only improves the properties of asphalt concrete but also solves the solid waste disposal problem in environment.

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