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Feasibility Study of Recycled Waste Plastic Application in Bituminous Concrete

Sotheany Seang^{1*}, Kuchvichea Kan¹, Masaaki Okamoto²

 Faculty of Civil Engineering, Institute of Technology of Cambodia, Russian Federation Blvd., P.O. Box 86, Phnom Penh, Cambodia
 ² IKEE Bitumen Chemical (Cambodia) Co., Ltd, Lot No. P2-094-A, Phnom Penh Special Economic Zone, National Road No.4, Khan Posenchey, Phnom Penh, Cambodia

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Abstract: The road is one of the most fundamental forms of social infrastructure and plays a critical role in boosting the local economy. However, the route has been used in many different loading types, affecting their performance. The increase in traffic in commercial vehicles is the main factor causing road damage. This problem involves us thinking about improving the pavement characteristic and quality by using polymer modification materials that satisfy both the strength and economic aspects. Thus, this study aims to find the best combination of bitumen and plastic for long-term performance by comparing the stability of conventional and modified bituminous concrete and investigating the behavior of bituminous concrete mixed with bottle caps as recycled plastic waste in the wet and dry processes. The various percentage of recycled plastic waste of bottle caps of 2%, 4%, 6%, 8%, 10% of the binder, and 3%, 4%, 5%, 6%, 7%, 8% of the binder are used in the dry process and wet process, respectively. The sample of experiment preparation was mixed with a selection bitumen 60/70 and aggregate blending (ASSHTO T 27) of fine and coarse aggregate sieve analysis. Marshall test properties such as Stability, Flow value, Air void, etc., are used to determine the optimum recycling of plastic waste content. The result indicated that the modified binder provides better engineering properties for the wet and dry processes. The recommended proportion of plastic used in the wet process is between 4% to 6% of bitumen content due to the characteristic of the binder and the marshall test result. The recommended proportion of plastic used for the dry process is 6%. It improves the base bitumen and stability, which resist deformation, rutting, and shear stress.

Keywords: Bituminous Concrete, Modified Bitumen, Plastic Bottle Cap, Wet Process, Dry Process, Marshall test

1. INTRODUCTION

The road is one of the most fundamental forms of social infrastructure and plays a critical role in boosting the local economy. The continuous growth in commercial vehicle traffic, including the considerable change in daily and seasonal temperature, demand enhanced road characteristics. As a result, road pavement enhancement research is required to ensure the upcoming generations' survival [1]. Bitumen binder and aggregate are commonly utilized to produce bituminous concrete for road construction. The material used in the production of bitumen pavement is chosen to provide the most cost-effective solution to meet traffic and environmental demands.

The materials-aggregates, bitumen, and additives must be carefully selected. It is necessary to consider availability, costs, and the impact on performance [2]. Phnom Penh, Cambodia, faces a considerable waste management challenge due to the rapid economic and industrial growth. The waste has increased

the environmental impact by more than 3,000 tons, including 13.2% of the waste plastic generated daily [3]. Landfilling, incineration, and random littering are currently the most popular waste disposal options in cities, municipalities, and the countryside. Unfortunately, these disposal methods are harmful to human health and the environment, and as a result, rivers, gutters, and roadsides are clogged with waste plastics. In a developing country, plastic waste is a serious problem that can impact the economy and the environment [4]. Previous researches have mentioned the possibility of strengthening the performance of bituminous concrete (BC) by using plastic such as polypropylene (PP) and polyethylene (PE). Adding the recycled plastic waste into the bitumen is known as modified bitumen, which improves the properties of bitumen. It enhances various properties (rutting resistance, wearingresistance, stripping resistance, oil resistance and durability, etc., Long-life pavement) of bitumen mixtures. Waste plastic polymers could be utilized as a long-term and cost effective component of

^{*} Corresponding author: Sotheany Seang

E-mail:sotheany_seang@gsc.edu.kh; Tel: +855-87 625 285

bitumen qualities and are challenging for the environment and the economy. Therefore, a massive increase in environmentally responsible plastic waste recycling by using waste materials instead of new resources has two significant advantages in the road construction industry: reducing costs and waste in landfills [5]. So, this research focuses on utilizing the Wate Plastic Bottle cap in the bitumen mix in the various mixing processes of the Dry Process and the wet process.

2. METHODOLOGY

The study aims to find the best combination of bitumen and plastic for long-term performance by comparing the stability of conventional and modified bituminous concrete and investigating the behavior of bituminous concrete mixed with bottle caps as recycled plastic waste in the wet and dry processes. The various percentage of recycled plastic waste of bottle caps of 2%, 4%, 6%, 8%, 10% of the binder, and 3%, 4%, 5%, 6%, 7%, 8% of the binder are used in the dry process and wet process, respectively. The process of the dry is known as the aggregate extender which mixed between the material of the blending aggregate and the plastic together before added the bitumen 60/70. For the wet process, is the method of combine the bitumen with the plastic known as modified bitumen and then mixed with the aggregate.

2.1. Materials

a) Bitumen 60/70

Bitumen 60/70 was selected as the bituminous material in this research. The test performance of the laboratory to evaluate the properties were ductility, softening and penetration, and density. Table 1 indicates the properties of the bitumen 60/70.

b) Aggregate

The mineral aggregates were taken from Takream Mountain, located North-West of Cambodia. The laboratory test performance of the coarse aggregate and fine aggregate were specific gravity, water absorption (AASHTO T 85), abrasion loss (ASTM C 131), and flat and elongated particle (ASTM D 4791), as shown in The Ministry of Public Works and Transports specification defined the gradation of wearing coarse, as shown in Fig. 1.

c) Recycled waste plastic of bottlecap

The plastic polyethylene terephthalate(PET) bottle cap is an assembly of commingled plastic from post-consumer recycling operation, which includes various types of plastic, including polypropylene (PP), low-density polyethylene (LDPE), and linear low-density polyethylene (LLDPE). For the plastic bottle cap, the heating testing at 180°C for 90min showed the exciting

result of the melting plastic that contains is suitable as the period for mixing the Modified Bitumen. Noticeably, Only RPW consisting of the melting point below 200°C was considered a suitable material for bitumen modification. Table 3 indicates the properties of plastic bottle caps used in this experiment.

Table 1 The physical properties of Bitumen 60/70

Property	Test Method	Spec	Result	Unit
Ductility Test	ASTM_D113	>100	150	cm
Softening Point	ASTM_D36	45-55	50.2	°C
Penetration Test at 25°C	ASTM_D5	60-70	66.72	0.1 mm
Density	ASTM_D70	-	1.032	g/cm ³



Fig.1. Blending propotion of aggregate

2.2. Laboratory test

This study selected two effective mixing methods for mixing recycled plastic waste with bituminous concrete. The two processes included the Dry Process and the Wet Process. The binder content of 4.7% was used as the optimum bitumen content for both methods as it is the most effective proportion of binder content.

2.2.1. Sample preparation

The proper design of aggregate blend proportion and the optimum binder content were determined to ensure the excellent performance of the bitumen mixture. Twenty-one samples each

	Property	Test Method	Unit	19-12.5	12.5-5	0-5	Sand	Specification
	Bulk (Dry Basis)		(g/cm^3)	-	-	2.566	2.581	-
Specific Gravity	Bulk (SSD)	AASHTO	(g/cm^3)	-	-	2.603	2.617	-
0	Apparent	T85	(g/cm^3)	-	-	2.663	2.677	-
Water Ab	osorption		(%)	-	-	1.41	1.39	-
Abrasion	Loss	ASTM C 131	(%)	18.96	18.96	-	-	<40
Flat Partic	cle	ASTM D	(%)	12.00	21.19	-	-	<35
Elongated	Particle	4791	(%)	14.24	13.94	-	-	<35

Table 2 The physical properties of aggregate

of 1200g in weight were prepared according to the mix design to determine the optimum binder content. The various percentage of the bitumen binder (3%, 3.5%, 4%, 4.5%, 5%, 5.5%, 6%) was examined with the standard 75-blow Marshall design method using the automatic compaction machine. As a result, the selected optimum binder content was 4.7%. Thirty-six samples of bituminous concrete were prepared at the optimum binder content of 4.7% including the recycled waste plastic to test the effectiveness with the Dry processes and the Wet processes with the various percentages.

2.2.2. Drying process

The recycled waste plastic (RWP) of the PET bottle cap as dry solids in small particles, which has a maximum flake size of 5mm to 8mm to help produce a uniform dispersion, was added into the hot aggregate by blending before adding the bitumen in the dry process. For this experiment, the selection of recycled plastic waste was 2%, 4%, 6%, 8%, and 10% of the binder. The aggregate was heated at 170°C and mixed with recycled waste plastic as the plastic changed its state to the intermediate molten state and added with the pre-heated bitumen 60/70 of 150°C. The mixing of the bitumen with the recycled plastic waste was to coat the surface of the aggregate. The mixing temperature was around 158°C to 164°C, in which both materials of plastic and bitumen were in the liquid state based on the kinematic viscosity testing and the maximum melting point of the plastic.

2.2.3. Wet process

The wet process is the method of adding recycled plastic waste of PET bottle cap into the bitumen equivalent with a specific time and temperature known as modified Bitumen. The selection of plastic by weight of bitumen was 3%, 4%, 5%, 6%, 7%, and 8% used to investigate the change of the bituminous concrete. First, the bitumen 60/70 was heated to 150°C to ensure

that the bitumen was liquid, allowing the plastic to melt equally. Added the recycled waste plastic, increased the temperature between 180°C to 185°C for 90minute, and remained stirred the whole time.

After mixing, pre-heat the modified bitumen and aggregate to 160°C was selected to be combined with the modified bitumen due to changes in bitumen properties. The mixing temperature was around 158°C to 164°C, in which both materials of plastic and bitumen were in the liquid state based on the kinematic viscosity testing of base bitumen and the maximum melting point of the plastic.

Table 3 The properties of plastic bottle cap

Physical Attributes	Plastic Bottle Cap (CPE/PP)		
Melting Polymer of LDPE (°C)	112		
Melting Polymer of LLDPE (°C)	122		
Melting Polymer of PP (°C)	163		
Density (g/cm3)	0.93		
Water Contact Angle (° Degree)	109.3		
MFI (g/10min)	3.61		

3. RESULTS AND DISCUSSION

3.1. Physical properties of the normal and modified Bitumen

The properties of the bitumen mixing with the recycled waste plastic have been shown in Table 4. As the result shown, the more content of plastic, the ductility value and penetration value of bitumen had been decreased which shown the loss of cohesion ability of the bitumen and change the grade of the

bitumen causing the bitumen harder than the conventional bitumen. In the other hand, the softening point increase showed it more resistance to the higher temperature in the working periods.

Table 4 The property	erties of bitumen cont	ent various perce	entage of the
recycled waste pla	istic		

Sample No.	Plastic Content (%)	Penetration Value (mm)	Ductility Value (cm)	Softening Value (°C)
1	0	66.72	150	50.2
2	3	45.5	68.62	56.9
3	4	36.1	33.38	58.9
4	5	37	27.31	62.3
5	6	27.31	15.17	65.8
6	7	17.67	11.18	76
7	8	26.06	10.97	85.45

3.2. Bulk density

The result in Fig. 1 showed a decrease in the bituminous concrete (B.C.) mixtures of the bulk density compared to the conventional B.C. mixture in the dry process when the recycled waste plastic (RWP) is added. The general tread of the Wet Process also illustrates the contrary graph, which is an increase in bulk density while the percentage of RWP increases. Moreover, the bulk density decreased when it reached 6% of RWP content for the wet process.



Fig.1. Bulk density affected by plastic percentage

3.3. Void of mineral aggregate

The percentage of voids mineral aggregate (VMA) is the percentage of void space between the granular particle in the specimen. The result shown in Fig. 2 indicates the increase of the VMA in the B.C. mixture for both processes. VMA is counterproductive and detrimental to pavement quality because inadequate VMA of asphalt results in the asphalt concrete bleeding and low durability.

3.4. Air void

Air voids are the airspace between the aggregate particle in the final compacted mix. The advantage of the air voids is to allow additional compaction under traffic. Usually, the allowable percentage of the air voids is between 2% to 4%. The dry process results indicate that using recycled waste plastic as a modified asphalt affects the air void of the B.C. mixture, which increases the air void of the mix. In contrast, for the wet process, air voids were decreased at the first 6% and recovered little by little along with the increase of the plastic content. This result may show the maximum plastic Content in the bitumen that can be mixed. However, more tests should be conducted to verify the maximum plastic combined with the bitumen. Fig. 3 illustrates the result of air void in both dry and wet processes.



Fig. 2. Void of mineral aggregate affected by plastic percentage

3.5. Void fill with Bitumen

Fig. 4 illustrates the void fill with bitumen against the increase of plastic in both processes. Generally, it can be seen that the voids filled with bitumen increase with increasing bitumen content. For the dry process, the graph showed the decrease of the VFB, which cause by the plastic forming a thin layer between aggregate and binder, resulting in reduced bitumen content. In the wet process, the result shows the increment to over 90% of VFB, which means the melting of the plastic in the bitumen is also in high percentage.



Fig. 3. Air voids affected by plastic percentage



Fig. 4. Voids fill with Bitumen affected by plastic percentage

3.6. Marshall stability and flow value

The Marshall stability at 60°C is the value resistance of the bituminous concrete to deformation, rutting, and shearing stress. Fig. 5 illustrates that the Marshall stability of using direct recycling waste plastic (wet process) into bitumen mixture shows their effective result of increasing the Marshall stability compared to the dry process. As a result, the dry process's marshall stability is nearly 17kN as the optimum strength, while the optimum power of the wet process is above 20kN and still shows the trend of remaining increases. So, the stability value of both methods of the mixtures met the government specification of Cambodia of not less than 7kN. The result indicated that the wet mixing process provides a more significant influence than the dry process. However, the increase in stability can improve adhesion between the binder and the aggregate. However, more tests like the indirect tensile fatigue test, etc., would be conducted in future studies to be confirmed.

The Marshall Flow value is referred to the maximum deformation of the bituminous concrete mixture to the maximum load. Fig. 6 shows the result of the flow value. The result in both processes illustrates; that the flow value is a slight change in the wet process. In contrast, the flow value increased for the dry process, and the recycled plastic waste content increased. It has to be said that the flow value does not explicitly reflect the permanent deformation resistance of the bituminous mixture. Further tests, including wheel tracking, should be carried out to evaluate the permanent deformation resistance. The increase of the flow value in the dry process may cause by the un-melting plastic Content in the bituminous mixtures.



Fig. 5. Marshall stability affected by plastic percentage



Fig. 6. Flow value affected by plastic percentage

For the dry process, the result of this research demonstrated the acceptable bitumen mixture performance, including the increased marshall stability, flow value, and air void, which also meet the requirement of the Cambodia Ministry of public work and transport (MPWT) specification as the Marshall stability is not less than 7.0 kN, the flow remains between 2mm to 4mm, the air voids in the mix is 3% to 5%, the voids in mineral aggregate is 10% to 14%, and void fill with bitumen is 65% to 80%. The air voids had showed that the method of the dry process is adequate to provide space for the expansion of bitumen binder to prevent bleeding and reduce skid resistance. Additionally, due to the plastic content shown a significant result of the Marshall stability between 6% and 8% of the recycled waste plastic content and better than the conventional bituminous concrete with the method of directly adding the solid plastic waste to the hot aggregate, it had been considered to be selected as an optimum plastic content, however the flow value also necessary to be considered because it may cause easily cracking or rutting to the road pavement. Ever thought the Marshall stability of 6% and 8% of RWP content is similar, the flow value of the 8% plastic showed a good result. Therefore, the recycled waste plastic content of 8% in the bituminous concrete was selected as the optimum plastic content to enhance the road characteristic and support the environment with the effect method of disposal the waste. However, using this process, the un-melting waste plastic content should be conducted for further investigation to control the road pavement quality.

The wet process considers non-linearity due to the change in the characteristic of the binder (Bitumen and Recycled Waste plastic). Additionally, the recycled waste plastic was used as bitumen replacement or bitumen modifiers in the wet process. Due to the modified bitumen being problematic initially requires a high temperature for mixing, which is affecting the bitumen behavior quality. The primary purpose of modified bitumen is to lessen the amount of asphalt binder in the mixture, which has the added benefit of reducing the quantity of the raw materials. Moreover, for the wet process, as mentioned by Mashaan et al. [6], a waste plastic content of 4% is achieved good properties of strength, stability, stiffness, durability, and rutting resistance and for the 6% of plastic waste is vital to increase the fatigue life and cracking resistance. As the result obtained from the study had shown the strong road enhancement due to the increase of the Marshall stability of the bituminous concrete mixture. In case of the comparison between conventional and modified bituminous concrete in the wet process, it shown that modified bituminous concrete by using the plastic polymer provide incredible result which better than normal bituminous concrete, also partially reduce the waste and support the environments. The flow value in this process had been shown satisfy result with the flow value is not so much effect of the plastic and remained similar to the normal bitumen. Even though the plastic had impact to the characteristic of the bitumen but the value of the flow value is remaining as normal. Thereby, the modified bitumen positively influences the deformation, rutting resistance, and shearing stress of bituminous concrete. Whereases, the result of the air

void and the void fill with bitumen which also an importance result to make a conclusion of the quality of the bituminous mixture was shown un-satisfy result base on the MPWT specification which is highly decrease of the air void and hug increase of the void fill with bitumen. In conclude, from the current result obtained, it cannot be making any clear conclusion of the optimum of plastic content for the wet process, yet. Moreover, the graph of the Marshall stability shows it continuously increase which may require to conducted some more samples test of increasing the plastic content to reach the optimum value of the Marshall stability. Additionally, due to the wet process is a method that strongly effect to the physical properties of the bitumen, another specification for the use of the bitumen modification should be selected for this method that require the trial construction at the actual site condition to verify the working ability and the failure effected by the plastic content and other experiments also should be conducted to ensure the quality of the road pavement to avoid cracking the high traffic volume. Also, the trial construction should be conduct more to make a standard specification of using modified bitumen in the road pavement.

4. CONCLUSION

The addition of recycled waste plastic of PET bottle caps material used in the bituminous concrete is recommended due to the enhance the overall performance of the binder due to the increase of the bituminous mix compared to the conventional bituminous concrete. The recycled plastic of PET bottle caps showed significant improvement in the physical properties of base bitumen. For the modified bitumen of the wet process, the softening point increased while the ductility and penetration decreased. The result has shown that the stability improved after adding the waste plastic for both the dry and wet processes. It also provides increased properties related to stiffness. Bitumen can be reduced for the plastic that melts, which causes a higher solids content at use temperature. Therefore, using recycled waste plastic in a bitumen mixture reduces the pavement deformation and rutting resistance and influences the adhesion between the bitumen and the aggregate, and support the environment with the method of reused and reduces plastic waste. Thereby, both processing provides different benefits on the road construction sector based on the actual condition requirement. However, the dry process indicated the suitable result of the bituminous mixture for the usage for the Cambodia specifications whereases for the wet process still require a lot more test and a separate specification due to the change of the binder behavior used.

In this experiment, the feasibility study of using recycled waste plastic in bituminous concrete in both methods of Wet and Dry process demonstrated as following:

• The optimum plastic content for the dry process is 8% due to the optimum point of the stability test in this process with the acceptable to the MPWT of Cambodia specification.

- The optimum plastic content in the wet process is not be able to selected yet due to the result have shown the continuously increase of the Marshall stability. So, more test is required to be further conducted.
- The stability value showed an increase in the addition of recycled waste plastic compared to conventional bituminous concrete.
- The wet process will substantially affect the air voids in the bituminous concrete more than the dry process and also highly effect to the Marshall stability.

It can be concluded that plastic waste has great potential to be used as a modifier in the bitumen for road application. However, it is expected that the storage stability has not yet been evaluated in the present research and needs to be further investigated to avoid issues at the plant and on-site for the wet process while the dry process was confirmed as an easy method for manufacturing for road construction.

The result obtained from the present investigations shows the superiority of recycled plastic waste modified mixes over conventional mixes. Therefore, recycled plastic waste and bitumen combinations may recommend for heavy traffic roads.

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REFERENCES

- Bhardwaj, A., Keshav, B. K., & Singh, A. (2017). Review Paper on Application of Waste Plastic in Modifying Bitumen Properties. International Journal of Engineering Research and Applications, 07(04), 79–81. https://doi.org/10.9790/9622-0704047981
- [2] Hansen, K., McGennis, R., Prowell, B., & Stonex, A. (2000). Current and Future Use of Non-bituminous components of Bituminous Paving Mixtures. Transportation in the New Millenium, A3B05: Com, 6. http://onlinepubs.trb.org/onlinepubs/millennium/00079. pdf
- [3] Yagasa, R., Uch, R., & Sam, P. (2019). Solid Waste Management in Cambodia. 27, 56–85. https://doi.org/10.4018/978-1-7998-0198-6.ch003
- [4] Beresford, N. (2023). Project Title: Combatting Marine Plastic Litter in Cambodia Implementing Partner: National Council for Sustainable Development Start Date January 2021 End Date: July 2023 L PAC Meeting Date: 10 December 2020 Brief Description The project aims to prove. December 2020.
- [5] Mashaan, N. S., Chegenizadeh, A., Nikraz, H., & Rezagholilou, A. (2021). Investigating the engineering properties of asphalt binder modified with waste plastic polymer. Ain Shams Engineering Journal, 12(2), 1569– 1574. https://doi.org/10.1016/j.asej.2020.08.035
- [6] Mashaan, N., Chegenizadeh, A., & Nikraz, H. (2021). Laboratory properties of waste PET plastic-modified asphalt mix. Recycling, 6(3), 4–13. https://doi.org/10.3390 /recycling6030049